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(54) **MANAGEMENT OF HEAT CONDUCTION USING PHONONONIC REGIONS FORMED WITH VOID NANOSTRUCTURES**

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(57) **ABSTRACT**

A gas turbine engine component formed of material having phononic regions. The phononic regions are formed of void nanostructures. The phononic regions modify the behavior of the phonons and manage heat conduction.

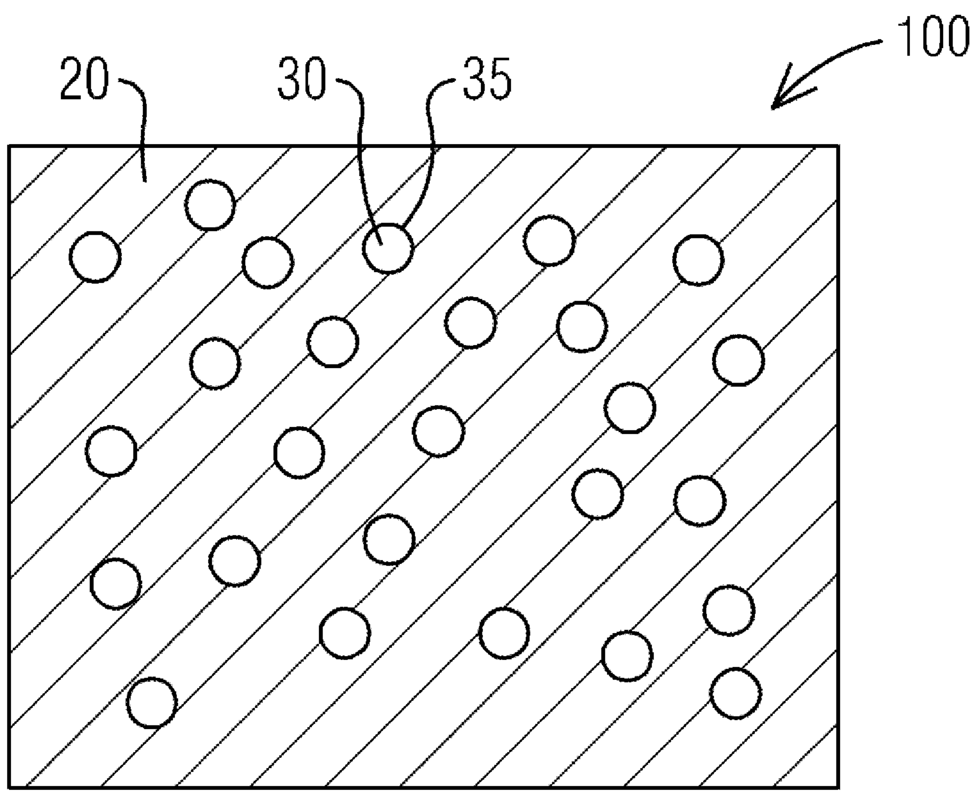


FIG. 1

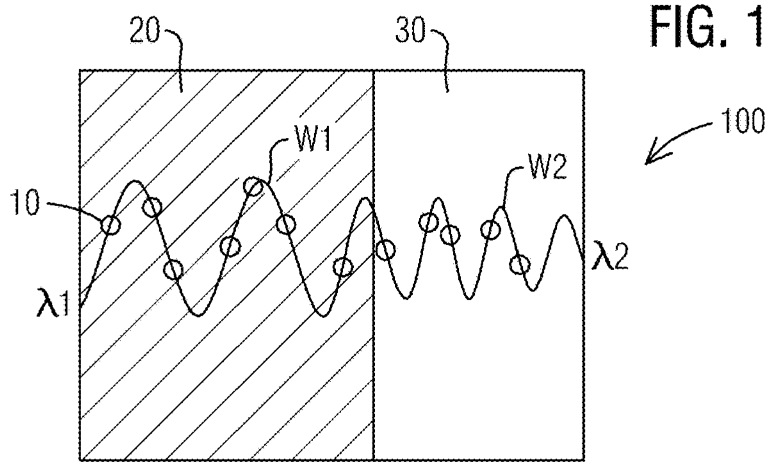


FIG. 2

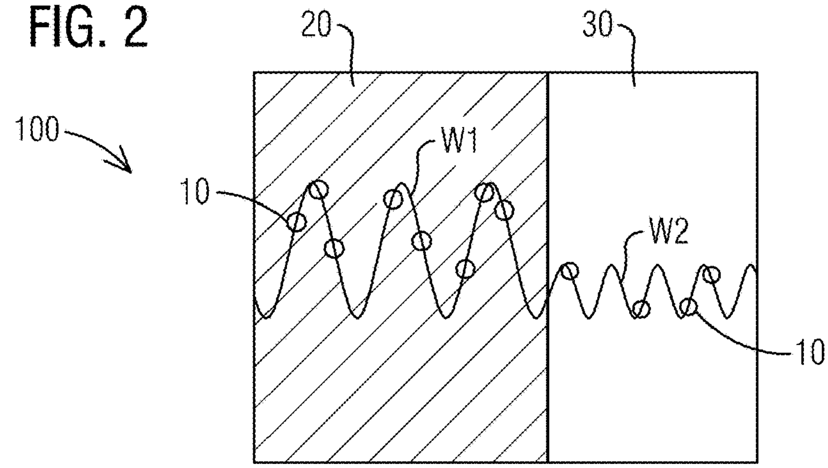


FIG. 3

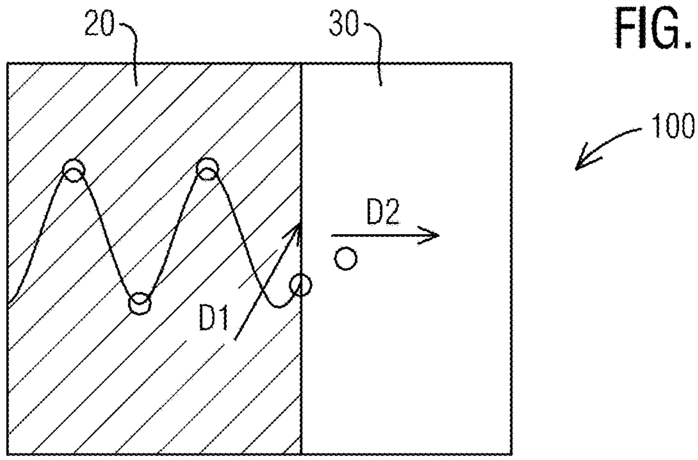


FIG. 4

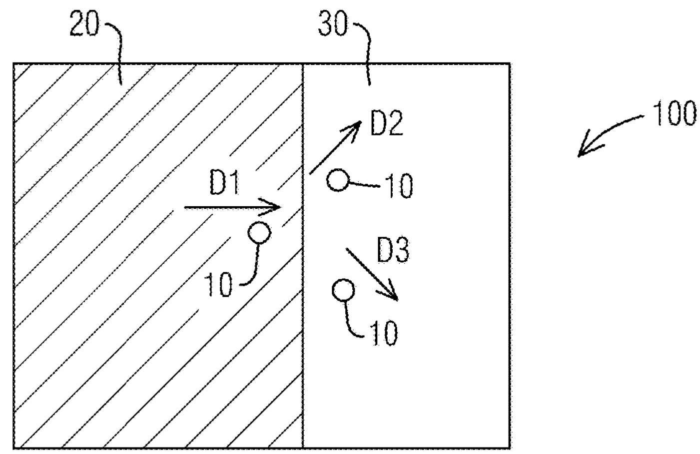


FIG. 5

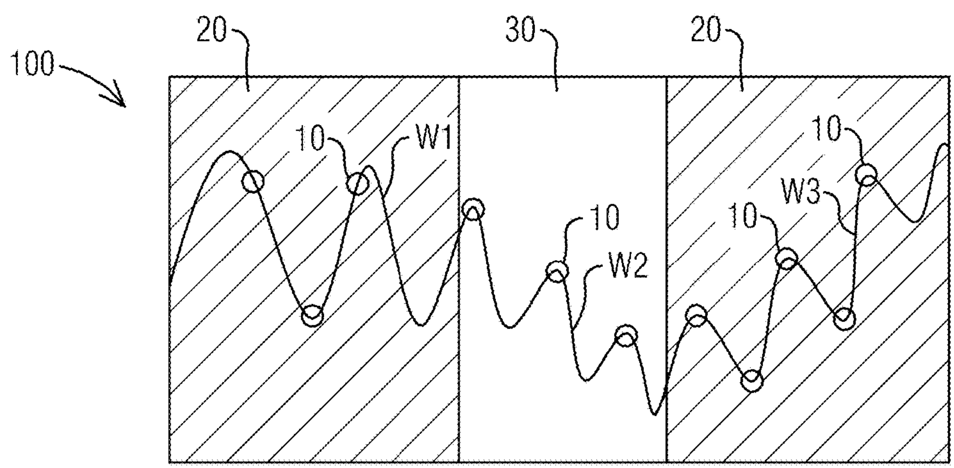


FIG. 6

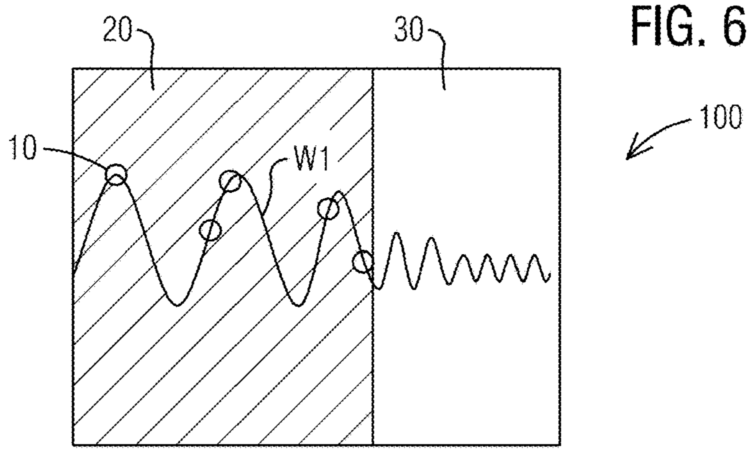


FIG. 7

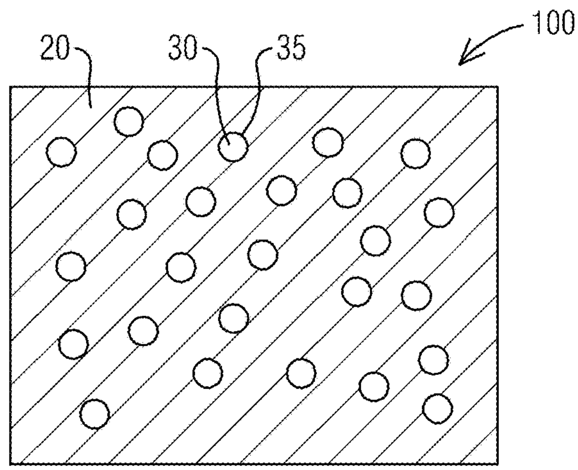


FIG. 8

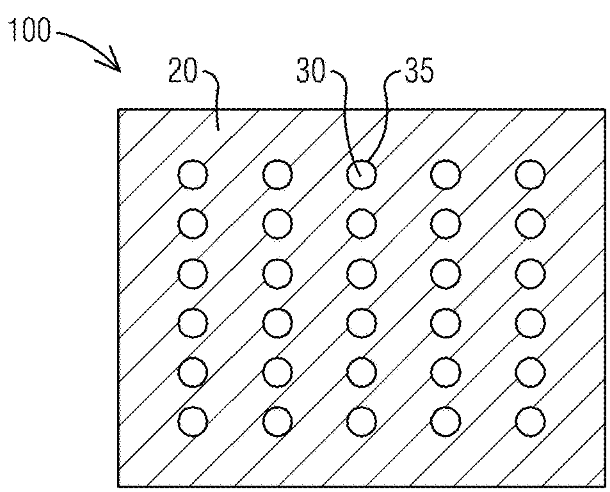


FIG. 9

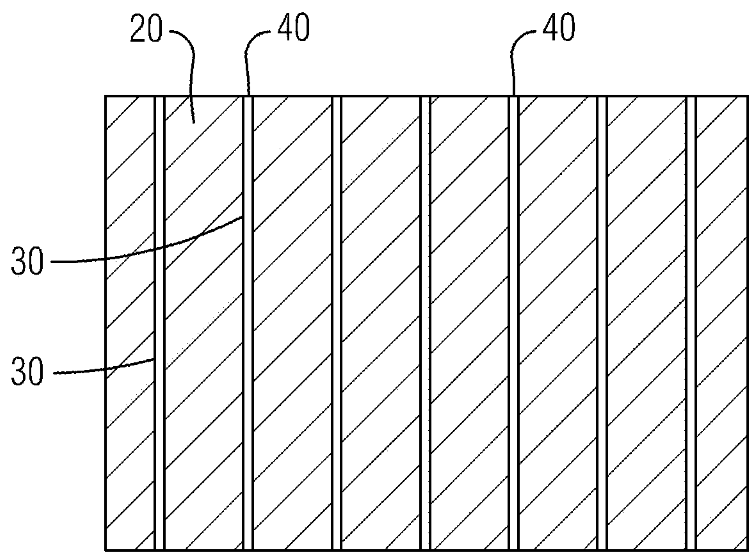


FIG. 10

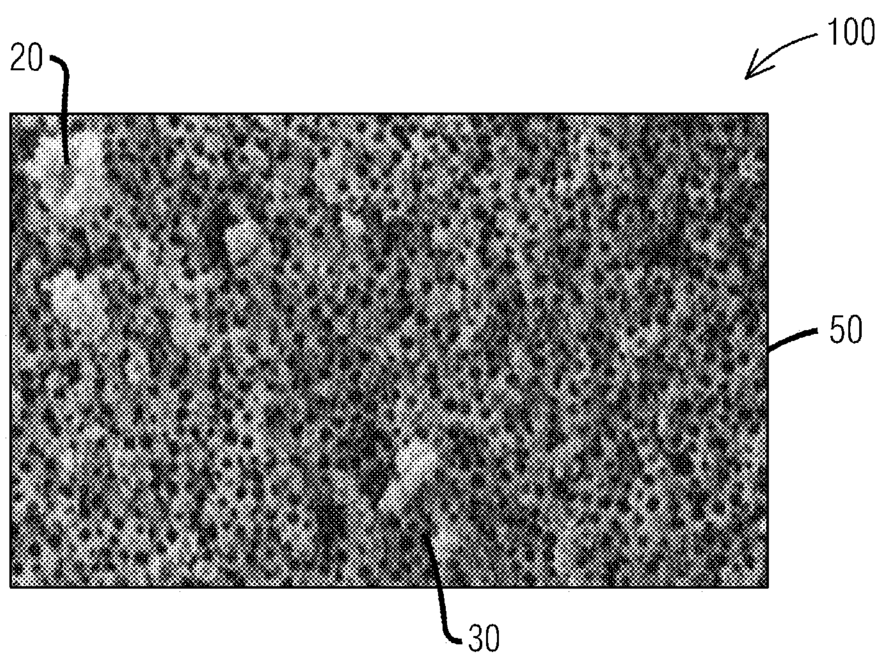


FIG. 11

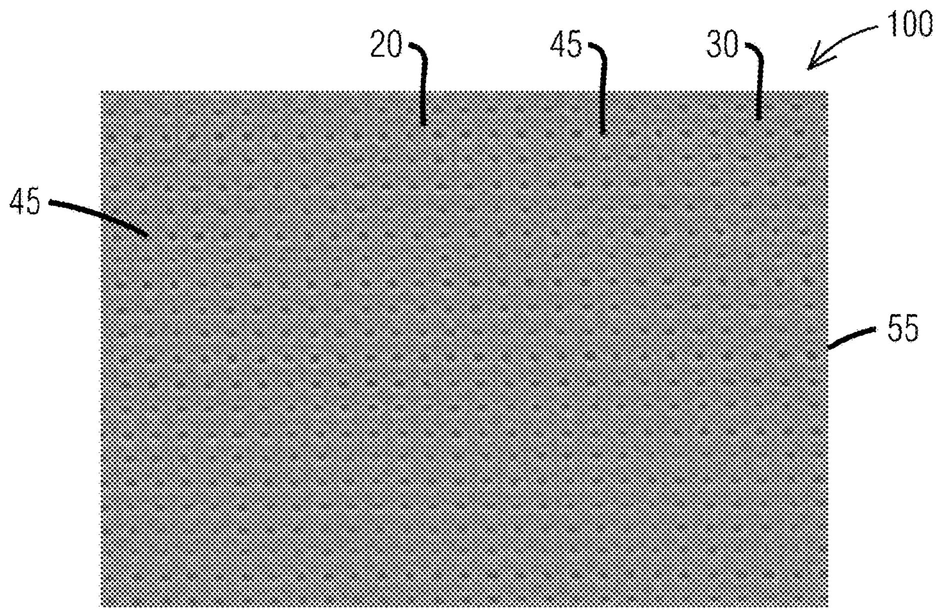
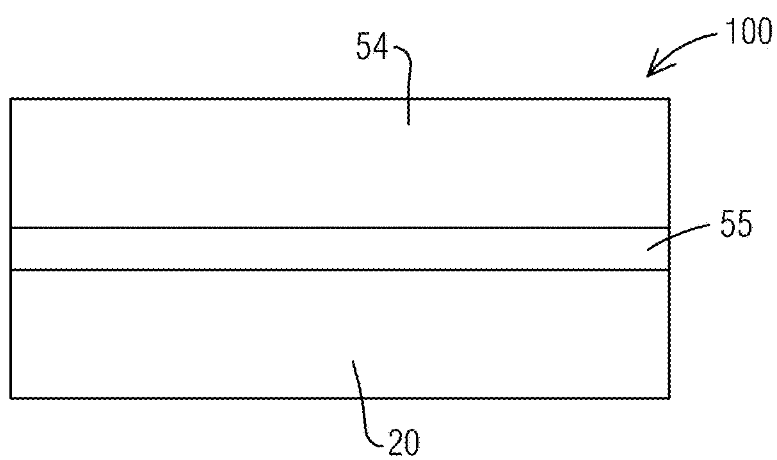


FIG. 12



MANAGEMENT OF HEAT CONDUCTION USING PHONONONIC REGIONS FORMED WITH VOID NANOSTRUCTURES

BACKGROUND

[0001] Disclosed embodiments are primarily related to gas turbine engines and, more particularly to phonon management in gas turbine engines. However, the disclosed embodiments may also be used in other heat impacted devices, structures or environments.

2. Description of the Related Art

[0002] Gas turbines engines comprise a casing or cylinder for housing a compressor section, a combustion section, and a turbine section. A supply of air is compressed in the compressor section and directed into the combustion section. The compressed air enters the combustion inlet and is mixed with fuel. The air/fuel mixture is then combusted to produce high temperature and high pressure gas. This working gas then travels past the combustor transition and into the turbine section of the turbine.

[0003] Generally, the turbine section comprises rows of vanes which direct the working gas to the airfoil portions of the turbine blades. The working gas travels through the turbine section, causing the turbine blades to rotate, thereby turning a rotor in power generation applications or directing the working gas through a nozzle in propulsion applications. A high efficiency of a combustion turbine is achieved by heating the gas flowing through the combustion section to as high a temperature as is practical. The hot gas, however, may degrade the various metal turbine components, such as the combustor, transition ducts, vanes, ring segments and turbine blades that it passes when flowing through the turbine.

[0004] For this reason, strategies have been developed to protect turbine components from extreme temperatures such as the development and selection of high temperature materials adapted to withstand these extreme temperatures and cooling strategies to keep the components adequately cooled during operation.

[0005] Some of the components used in the gas turbine engines are metallic and therefore have very high heat conductivity. Insulating materials, such as ceramic may also be used for heat management, but their properties sometimes prevent them from solely being used as components. Therefore, providing heat management to improve the efficiency and life span of components and the gas turbine engines is further needed. Of course, the heat management techniques and inventions described herein are not limited to use in context of gas turbine engines, but are also applicable to other heat impacted devices, structures or environments.

SUMMARY

[0006] Briefly described, aspects of the present disclosure relate to materials and structures for managing heat conduction in components. For example gas turbine engines, kilns, smelting operations and high temperature auxiliary equipment.

[0007] An aspect of the disclosure may be a gas turbine engine having a gas turbine engine component having a first material, wherein phononic transmittal through the first material forms a first phononic wave; and a phononic region located within the gas turbine engine component, wherein the phononic region is a void nanostructure formed in the first material, wherein phononic transmittal through the void nanostructure modifies behavior of the phonons of the first phononic wave thereby managing heat conduction.

[0008] Another aspect of the present disclosure may be a method for managing heat conduction in a gas turbine engine comprising forming a phononic region by forming a void nanostructure in a first material of a gas turbine engine component, wherein phononic transmittal through the first material forms a first phononic wave; and modifying behavior of phonons transmitted through the first material when the phonons are transmitted to the void forming the phononic region thereby managing heat conduction.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] FIG. **1** is a diagram of phonons interacting with a phononic region where a wave property is modified.

[0010] FIG. **2** is a diagram of phonons interacting with a phononic region where the mode of propagation is altered.

[0011] FIG. **3** is a diagram of phonons interacting with a phononic region where the movement direction of the phonon is changed.

[0012] FIG. **4** is a diagram of phonons interacting with a phononic region where the phonons are scattered.

[0013] FIG. **5** is a diagram of phonons interacting with a phononic region where waves are refracted.

[0014] FIG. **6** is a diagram of phonons interacting with a phononic region where the phonons are dissipated.

[0015] FIG. **7** is a diagram illustrating a material having phononic regions formed of void nanostructures that are void spheres in a random distribution.

[0016] FIG. **8** is a diagram illustrating a material having phononic regions formed of void nanostructures that are void spheres in an ordered arrangement.

[0017] FIG. **9** is a diagram illustrating boundaries of phononic regions of void nanostructures that are void columns.

[0018] FIG. **10** shows an example of a nanomesh formed on the material of a gas turbine engine component.

[0019] FIG. **11** shows an example of a nanomesh grid formed on the material of a gas turbine engine component.

[0020] FIG. **12** shows a diagram of a nanomesh grid formed on the material of a gas turbine engine component.

DETAILED DESCRIPTION

[0021] To facilitate an understanding of embodiments, principles, and features of the present disclosure, they are explained hereinafter with reference to implementation in illustrative embodiments. Embodiments of the present disclosure, however, are not limited to use in the described systems or methods.

[0022] The items described hereinafter as making up the various embodiments are intended to be illustrative and not restrictive. Many suitable items that would perform the same or a similar function as the items described herein are intended to be embraced within the scope of embodiments of the present disclosure.

[0023] As disclosed herein, the materials used in the gas turbine engines permit the thermal conductivity of pieces to be modified, such as by being reduced in size, without changing the chemical structure in the majority of the material. Management of heat conduction can be achieved through nanostructure modification to portions of the existing gas turbine engine components. There is no need for a large scale bulk material or chemical changes; however smaller scale modifications consistent with aspects of the instant invention may be made to gas turbine engine components.

[0024] FIG. **1** shows a diagram illustrating the transmission of phonons **10** into a material **20** that is forming part of a gas turbine engine component **100** that can be used in a gas turbine engine. The gas turbine engine component **100** may be a transition duct, liner, part of the combustor, vanes, blades, rings and other gas turbine structures for which heat management would be advantageous. It should also be understood that in addition to gas turbine engine components **100**, the management of heat conduction disclosed herein can be applied to other devices for which heat management is important, for example, marine based turbines, aerospace turbines boilers, engine bells, heat management devices, internal combustion engines, kilns, smelting operations and any other item wherein heat conduction is a design consideration.

[0025] The material **20** discussed herein is a metallic material, however it should be understood that other types of materials may be used, such as ceramic, metallic glasses and composite materials, when given due consideration for their material properties consistent with aspects of the instant invention. A phonon **10** is generally and herein understood and defined as a quantum of energy associated with a compressional, longitudinal, or other mechanical or electromechanical wave such as sound or a vibration of a crystal lattice. Transmissions of phonons **10** collectively transmit heat. The transmissions of phonons **10** form waves in the material **20** as they propagate through the material **20**.

[0026] In FIG. **1**, the phonons **10** are transmitted through the material **20** at a first phononic wave W**1**. Formed in the material **20** is a phononic region **30**. The phononic region **30** is designed to modify the behavior of the phonons **10** as they propagate in the one dimensional (1D), two dimensional (2D) and/or three dimensional (3D) spatial regions in the material **20**. The phononic region **30** may modify the behavior of phonons **10** so that they scatter, change direction, change between propagation modes (e.g. change from compression waves to travelling waves), reflect, refract, filter by frequency, and/or dissipate. The modification of the behavior of the phonons **10** manages the heat conduction in the gas turbine engine component **100**. The phononic region **30** is a void nanostructure formed within the material **20**. The void nanostructure is designed to be placed within the material **20** in such a manner as to modify the behavior of phonons **10** as they propagate through the material **20** so that heat conduction through the material **20** is controlled. The void nanostructures can be formed as divots, void spheres, void channels or other modifications to the material.

[0027] Still referring to FIG. **1**, the modification of behavior of the phonons **10** by the phononic region **30** may create a second phononic wave W**2**. For example, the first phononic wave W**1** propagates through the material **20**. As the first phononic wave W**1** propagates through the material **20** the first phononic wave W**1** may have the property of having a first frequency λ_1. When the first phononic wave W**1** interacts with the phononic region **30** the behavior of the phonons **10** may form a second phononic wave W**2** having the property of having a second frequency λ_2. As the phonons **10** exit from the phononic region **30** and propagate through the material **20** they may continue to propagate at the first frequency λ_1.

[0028] The transition from the first frequency λ_1 to the second frequency λ_2 and then back to the first frequency λ_1, helps manage the heat conduction in the material **20**. Further, by interspersing the material **20** with a number of phononic regions **30** the fluctuation can disrupt the transmission of phonons **10** through the material **20** so as to manage the propagation of phonons **10**.

[0029] FIG. **2** shows a phononic region **30** that modifies the behavior of the first phononic wave W**1** to a second phononic wave W**2** by changing the property of its mode of propagation. In FIG. **2** the first phononic wave W**1** is altered from a travelling wave to the second phonic wave W**2** which is a compression wave. However it should be understood that it is contemplated that compression waves could be modified to become travelling waves. By modifying the mode of propagation of the waves the heat conduction through the material **20** may be managed.

[0030] FIG. **3** shows a phononic region **30** that modifies the behavior of the phonons **10** by altering the direction of propagation. Phonons **10** may be moving in one direction D**1** through material **20** and then change direction to direction D**2** as they enter into phononic region **30**. By modifying the direction of movement of the phonons **10** the heat conduction through the material **20** may be managed.

[0031] FIG. **4** shows a phononic region **30** that modifies the behavior of the phonons **10** so that the phonons **10** are scattered when they enter the phononic region **30** from the material **20**. By scattering it is meant that each phonon **10** that enters the phononic region **30** in direction D**1** may propagate in a random different direction D**2**, D**3**, etc. By modifying the scattering of the phonons **10** the heat conduction through the material **20** may be managed.

[0032] FIG. **5** shows a first phononic wave W**1** moving through material **20**. When the first phononic wave W**1** reaches the phononic region **30** the first phononic wave W**1** is modified so that it is refracted and becomes second phononic wave W**2** as it passes through the phononic region **30**. As the second phononic wave W**2** exits the phononic region **30** the phononic wave W**2** may be refracted and become a third phononic wave W**3**. By having the phononic region **30** refract the first phononic wave W**1** the heat conduction through the material **20** may be managed.

[0033] FIG. **6** shows the phononic region **30** located within the material **20** causing phonons **10** from the first phononic wave W**1** to dissipate as it exits the material **20**. By "dissipate" it is meant that at least some of the phonons **10** cease to travel through the phononic region **30** or cease to exist. By having the phononic region **30** dissipate the phonons **10** the heat conduction through the material **20** may be managed.

[0034] FIG. **7** shows an example of the phononic region **30** formed by void nanostructures within the material **20**. It should be understood that the void nanostructure forms the entirety of the phononic region **30**. However, various phononic regions **30** may be formed from more than one type of void nanostructure. For example, as discussed herein the void nanostructure forming the phononic region **30** may be a void sphere **35** formed within the material **20**. In addition to a void sphere **35**, other shapes for the void nanostructures may be formed such as void channels **40** or nanovoid divots **45**, as well as, amorphous shapes or other polygonal shapes.

[0035] The material **20** may be metallic in nature and may form a gas turbine engine component **100** or the component of another device wherein heat management may be need.

Within the material **20** the phononic regions **30** may be formed as void spheres **35** within the material **20**. FIG. **7** shows the void spheres **35** randomly dispersed throughout the material **20**. The void spheres **35** may have a diameter of between 5 nm-1000 nm. The placement and size of the void spheres **35** is determined based upon how heat conduction in the gas turbine engine component **100** will be managed.

[0036] FIG. **8** shows an alternative embodiment of the phononic regions **30** formed of void nanostructures where the void spheres **35** are positioned within the material in an orderly manner. In this example the void spheres **35** are organized so that they form rows of the void spheres **35**. The void spheres **35** may have a diameter of between 5 nm-1000 nm. The placement and size of the void spheres **35** is determined based upon how heat conduction in the gas turbine engine component **100** will be managed.

[0037] FIG. **9** is an alternative embodiment having phononic regions **30** formed as void channels **40** within the material **20**. The void channels **40** may have a width of between 5 nm-1000 nm. The length of the void channel **40** may vary depending on the size of the gas turbine engine component **100**, however generally a size of between 100 um-10 cm is contemplated. However, the void channel **40** may be between 10 um and 100 cm. The placement and size of the void channels **40** is determined based upon how heat conduction in the gas turbine engine component **100** will be managed.

[0038] Introduction of sharp changes in the acoustic impedance experienced by phonons **10** propagating through the phononic regions **30** can be instantiated by the void spheres **35** or void channels **40** formed in the material **20**. The phononic regions **30** can be formed in various layers of the material **20**. When the phononic region **30** is incorporated into a subsection of a material **20** with resolutions in the 5-1000 nm range, the void nanostructures that form the phononic region **30** will cause the phonons **10** to behave in one of the manners discussed above in reference to FIGS. **1-6**. This size correlates with phononic vibration frequencies of approximately 500 GHz to 100 THZ. Because the phononic regions **30** will have differing phononic impedances than the material **20**, they will modify behavior of the propagating phonons **10** in the material **20**, thereby disrupting, reducing and/or managing heat conduction. These techniques can also be used to direct heat conduction in desired directions by creating paths of optimal propagation for heat-inducing phonons **10** that are surrounded by phononic regions **30**.

[0039] In each of the above possible ways of managing the heat conduction shown in FIGS. **1-6**, phonons **10** interacting with phononic regions **30** on the same scale as their wavelength, can modify behavior of phonons **10** to impede propagation of phonons **10** and thus manage heat conduction. The patterns formed by the phononic regions **30** can be used to obtain the modified behavior of the phonons **10** that is desired. For example, patterns of phononic regions **30** parallel to the propagation direction can channel the phonons **10**. Patterns of phononic regions **30** normal to the phonons **10** can reflect them. Patterns of phononic regions **30** at an angle with respect to the propagation direction can scatter or reflect at an angle, spots of acoustic impedance change could cause scattering, etc.

[0040] As discussed above the phononic regions **30** may be used in metals and other crystalline structures, as well as ceramics in which void nanostructures may be created. In metals especially at temperatures above 400° C., the majority carrier is electrons. The technique for modifying behavior of the phonons **10** is likely to manage phonons **10** directly more so than thermal free electrons in metals. However, electron propagation may also be affected by the phononic regions **30**, in two possible ways. One, electrons in metals are constantly exchanging their energies with phonons **10**, so management of the phonons **10** has an effect on electrical propagation. Two, if the electron propagation has any frequency component, it would likely be of similar frequencies as the phonon **10**, due to similar interactions that the electrons will have with crystalline structures. In metals control of phonons **10** may have significant impacts on heat conduction that is mediated by thermal free electrons.

[0041] FIG. **10** shows an example of a nanomesh **50** formed on material **20** of the gas turbine engine component **100**. In particular, for example, the nanonmesh **50** may be formed on the surface of a vane. The vane may be a modified vane from an existing gas turbine engine component **100**, or alternatively the vane may have been formed with the nanomesh **50**. Additionally the design of the vane may be modified from an existing vane design or alternatively designed in such a fashion so as to take advantage of the use of the nanomesh **50**. The dark spheres are phononic regions **30** that are void nanostructures formed as void spheres **35** within the material **20** of gas turbine engine component **100**. The void spheres **35** have diameters that fall within the range of 5-1000 nm. In the example shown the diameters may be in the range 250 nm-400 nm. By having the void spheres **35**, phonons **10** propagating through the material **20** impacting the nanomesh **50** can be managed. The nanomesh **50** can modify the behavior of the phonons **10** by disrupting the propagation and cause the phonons **10** to behave in the manner shown in FIGS. **1-6**. The desired behavior can be caused by arranging the nanonmesh **50** to form patterns in the material **20** that they can be used to manage heat conduction.

[0042] FIG. **11** shows an example of a nanomesh grid **55** formed on the surface of a material **20** on the gas turbine engine component **100**. For example, a nanomesh grid **55** may be formed on a transition duct. The transition duct may be a modified component from an existing gas turbine engine component **100**, or alternatively the transition duct may have been formed with the nanomesh grid **55**. Additionally the design of the transition duct may be modified from an existing combustor design or alternatively designed in such a fashion so as to take advantage of the use of the nanomesh grid **55**. The nanomesh grid **55** is formed from phononic regions **30** arranged as nanovoid divots **45** within the material **20**. The nanovoid divots **45** may be formed by lasers pock-marking the surface of the material **20** and then placing another layer of the material **20** on top of the layer with the nanovoid divots **40** formed. The nanovoid divots **40** may be formed so as to have a diameter of between 5-1000 nm. In the example shown the diameters of nanovoid divots **40** may be in the range of 10 nm-40 nm. By having the nanovoid divots **45**, the phonons **10** propagating through the material **20** impacting the nanomesh grid **55** can be managed. The nanomesh grid **55** can modify the behavior of the phonons **10** by disrupting the propagation and cause the phonons **10** to behave in the manner shown in FIGS. **1-6**.

[0043] FIG. **12** is diagram illustrating layered placement of a nanomesh grid **55** on a material **20** forming the gas turbine engine component **100**. For example, the nanomesh grid **55** may be formed on the interior surface of a combustor. The combustor may be a modified component from an existing gas turbine engine component **100**. Additionally the design of the combustor may be modified from an existing combustor design or alternatively designed in such a fashion so as to take advantage of the use of the nanomesh grid **55**.

[0044] On the surface of the material **20** the nanomesh grid **55** is formed. The thickness of the material **20** may be between 1 cm to 10 cm. The thickness of the nanomesh grid **55** may be between 5-1000 nm. The nanomesh grid **55** may be formed in one of the manners discussed above, for example the nanomesh grid **55** may be formed by adding nanovoid divots **40** to an existing gas turbine engine component **100**. On the surface of the nanomesh grid **55** a thermal barrier **54** may be placed. The thickness of the thermal barrier **54** may be between 1 mm to 5 cm. The thermal barrier **54** may be made of a heat resistant material, such as ceramic. Once formed the layered structure can be used to manage the propagation of the heat from the interior of the combustor. This can help reduce the stresses that heat may generate in the material **20** and can extend the life span of gas turbine engine components **100**.

[0045] While embodiments of the present disclosure have been disclosed in exemplary forms, it will be apparent to those skilled in the art that many modifications, additions, and deletions can be made therein without departing from the spirit and scope of the invention and its equivalents, as set forth in the following claims.

1-18. (canceled)

19. A gas turbine engine component comprising:

a first region of a first material; and

a phononic region comprising void nanostrcutures within the first material;

wherein phononic transmittal of phonons through the first material forms a first phononic wave having the phonons; and

wherein, upon transmittal of the first phononic wave to the phononic region, the phononic region is configured to modify a behavior of the phonons of the first phononic wave.

20. The gas turbine engine component of claim **19**, wherein the first phononic wave has a first property, wherein the phononic region is configured to the behavior of the phonons of the first phononic wave to form a second phononic wave having a second property different than the first property of the first phononic wave.

21. The gas turbine engine component of claim **20**, wherein the first property and the second property are frequency.

22. The gas turbine engine component of claim **20**, wherein the first property and the second property are modes of propagation.

23. The gas turbine engine component of claim **19**, wherein the phononic region modifies the behavior of the phonons of the first phononic wave so that the phonons of the first phononic wave change direction of propagation.

24. The gas turbine engine component of claim **19**, wherein the phononic region modifies the behavior of the phonons of the first phononic wave so that the phonons of the first phononic wave scatter.

25. The gas turbine engine component of claim **19**, wherein the phononic region modifies the behavior of the phonons of the first phononic wave so that the phonons of the first phononic wave are reflected, refracted, or dissipated.

26. The gas turbine engine component of claim **19**, wherein the phononic region is selected from the group consisting of a void sphere, a nanovoid divot, and void channel.

27. The gas turbine engine component of claim **26**, wherein the void nanostructures comprise void spheres having a diameter of from 5-1000 nm.

28. The gas turbine component of claim **27**, wherein the void spheres are formed in rows within the first material.

29. The gas turbine engine component of claim **26**, wherein the void nanostructures comprises void columns having a diameter of from 5-1000 nm.

30. A method for controlling heat conduction in a gas turbine engine comprising:

forming a phononic region within a first region of a first material of a gas turbine engine component, wherein the phononic region comprises void nanostructures;

transmitting phonons through the first material to form a first phononic wave having the phonons;

transmitting the first phononic wave to the phononic region, and

modifying a behavior of the phonons of the first phononic wave in the phononic region to manage heat conduction.

31. The method of claim **30**, wherein the first phononic wave has a first property, wherein the phononic region modifies the behavior of the phonons of the first phononic wave to form a second phononic wave having a second property different than the first property of the first phononic wave.

32. The method of claim **30**, wherein the first property and the second property are frequency or modes of propagation.

33. The method of claim **30**, wherein the modified behavior of the phonons of the first phononic wave is a changed direction of propagation of the phonons of the first phononic wave.

34. The method of claim **30**, wherein the modified behavior of the phonons of the first phononic wave is at least one of scattering, reflection, refraction, or dissipation of the phonons of the first phononic wave.

35. The method of claim **30**, wherein the phononic region is selected from the group consisting of a void sphere, a nanovoid divot, and void channel.

36. The method of claim **35**, wherein the void nanostructures comprise void spheres having a diameter of from 5-1000 nm.

37. The method of claim **36**, wherein the void spheres are formed in rows within the first material.

38. The method of claim **35**, wherein the void nanostructures comprise void columns having a diameter of from 5-1000 nm.

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