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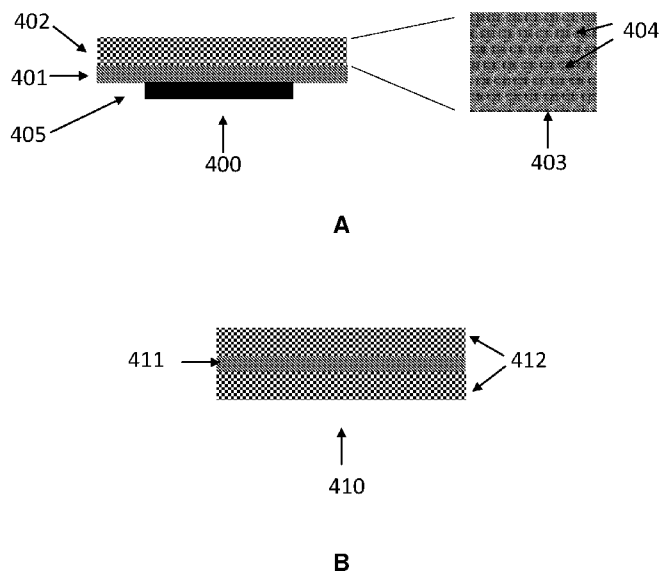


FIG. 4

(57) Abstract: A fine-array porous heat exchange material (503, 504, 513, 514, 613, 614, 712, 714, 1008), which comprises a plurality of pores having a substantially uniform size of <1000μm, with a variation of <20%, having a porosity of about 40-85%, and may comprise a metal or an alloy. A heat exchange apparatus (400, 500, 510, 903, 913) comprising a fine-array porous heat exchange material (503, 504, 513, 514, 613, 614, 712, 714, 1008) have significantly improved heat dissipation due to its dramatically increased surface areas and/or improved convection, and can be applied in a heat sink system (810, 900, 910, 1000) for cooling a LED light source (801) or a CPU processor (902) or in a heat radiation system for warming ambient from a heat source (1001).

HEAT EXCHANGE MATERIAL, APPARATUS AND SYSTEM

BACKGROUND

- [001] A heat exchange apparatus typically transfers heat from a heat source to a medium, such as air, water, oil or a refrigerant. Heat exchange apparatuses have been widely used in various mechanic and electronic devices in industries such as air conditioning, refrigeration, and power plants, refineries, and sewage treatment.
- [002] A heat exchange apparatus is typically designed to increase surface areas in order to facilitate convection for better dissipation of heat from a heat source. Metal foams are a porous heat exchange material that is often employed to construct heat exchange apparatuses because their high porosity leads to both increased heat-dissipating surface areas and better convection.

SUMMARY

- [003] The present disclosure relates to a heat exchange material, and specifically to a fine-array porous heat exchange material, and also to its application in heat exchange apparatuses or systems.
- [004] Disclosed herein provides a heat exchange material for use in a heat exchange apparatus, such as a heat exchanger or a heat sink. The heat exchange material typically comprises a fine-array porous material, composed of a metal, such as Ni, Al, Cu, Au, Ag, Ti or Fe, or of an alloy, such as an aluminum alloy, a copper alloy or a nickel alloy, or of a metal/metal oxide composite, such as Ti/TiO₂ and Al/Al₂O₃. The fine-array porous material comprises a plurality of pores, wherein the plurality of pores have a size of less than about 5000 μm ; the size of the plurality of pores is substantially uniform with a variation of less than about 20%; and the fine-array porous material has a porosity of about 40-85%. In some preferred embodiments, a heat exchange material may comprise a fine-array porous material having a porosity of about 74%. Compared with conventional and metal foam heat exchange materials, such a fine-array porous heat exchange material can achieve a much better conduction/radiation-mediated heat dissipation because of a much higher heat dissipating surface area due to the significantly higher surface-area-to-volume ratio of the fine-array porous heat exchange material. In embodiments where the fine-array porous material is composed of a metal/metal oxide composite, such as Ti/TiO₂ and Al/Al₂O₃, besides the above mentioned advantages, the fine-array porous heat exchange material as such can also achieve greatly improved thermal radiation, attributable primarily to the

presence of metal oxide on the outer surface of the metallic fine-array porous heat exchange material. This advantage is especially important in situations where efficient convection cannot to be achieved and thermal radiation is a primary way of heat dissipation.

[005] Disclosed herein also includes a heat exchange apparatus that comprises a fine-array porous heat exchange material as disclosed above. The heat exchange apparatus typically includes a heat conduction layer and at least one heat dissipation layer. The heat conduction layer typically comprises a heat conductive material, composed of a metal, an alloy, a heat-conductive ceramics, or a heat-conductive polymer; each of the at least one heat dissipation layers comprises a fine-array porous heat exchange material as disclosed above. The heat conduction layer is disposed on and thermally contacts the at least one heat dissipation layer to thereby thermally transfer heat from a higher temperature medium in contact with the heat conduction layer to a lower temperature medium in contact with the at least one heat dissipation layer.

[006] In some embodiments, a heat exchange apparatus may include only one heat dissipation layer, comprising one type of fine-array porous heat exchange material. In some other embodiments, a heat exchange apparatus may comprise two heat dissipation layers: a first heat dissipation layer and a second heat dissipation layer, comprising two types of fine-array porous heat exchange materials with different pore sizes. The first heat dissipation layer typically has a smaller pore size and is disposed on and thermally contacts the heat conduction layer, whereas the second heat dissipation layer has a larger pore size than the first heat dissipation layer and is disposed over the first heat dissipation layer. This configuration allows the favorable establishment of a heat gradient along the direction of air flow within the pores from the first heat dissipation layer to the second heat dissipation layer, thereby achieving an efficient convection-mediated heat dissipation. In some embodiments, the second heat dissipation layer and the first heat dissipation layer has a pore size ratio of about 2:1 - 1000:1; and the second heat dissipation layer and the first heat dissipation layer has a thickness ratio of about 0.01:1 - 1000:1, the thickness ratio depending on the pore sizes of the first heat dissipation layer and of the second heat dissipation layer.

[007] In some embodiments, a heat exchange apparatus may be a heat sink, including a heat sink main body and at least one heat dissipation layer, each of the at least one heat dissipation layer comprising one type of fine-array porous heat exchange materials as disclosed above. The heat sink main body comprises a base and an array of extrusions, wherein the array of extrusions are configured to extend from the base and are spaced apart with open gaps; and the at least one heat dissipation layer is coated on the heat sink main body. The array of extrusions of the heat sink main body may be an array of fins or an array

of pins, and may have a flared configuration to improve convection-mediated heat dissipation. According to some embodiments of a heat exchange apparatus as such, the array of fins may comprise an array of alternately placed long and short fins, forming a more dense array at the base end and a more loose array at the open end, allowing a favorable formation of heat gradients from the base end to the open end to thereby achieve a more efficient convection cooling.

[008] According to some embodiments of a heat exchange apparatus, the heat conduction layer and the at least one fine-array porous heat dissipation layer may take a form of enclosed tube and the heat exchange apparatus essentially forms a heat exchanger tube such as a condenser. In some embodiments, the heat conduction layer is disposed on an inside face of the heat exchange apparatus; and the at least one fine-array porous heat dissipation layer is disposed on an outside face of the heat exchange apparatus to thereby thermally transfer heat from a higher temperature medium inside the heat exchange apparatus to a lower temperature medium outside the heat exchange apparatus. Yet in some other embodiments, the heat conduction layer is disposed on an outside face of the heat exchange apparatus; and the at least one fine-array porous heat dissipation layer is disposed on an inside face of the heat exchange apparatus to thereby thermally transfer heat from a higher temperature medium outside the heat exchange apparatus to a lower temperature medium inside the heat exchange apparatus.

[009] This disclosure also provides a heat sink system for cooling a LED light source in a LED light assembly. The heat sink system substantially comprises a heat exchange apparatus, which provides a housing for and thermally contacts the LED light source. The heat exchange apparatus may comprise an inner heat conduction layer and an outer heat dissipation layer, wherein the outer heat dissipation layer comprises substantially a fine-array porous heat exchange material as disclosed above and is disposed on and thermally contacts the outside face of the inner heat conduction layer. By this configuration, the inner heat conduction layer can efficiently transfer heat from the LED light source to the outer heat dissipation layer for dissipation into the air. In some embodiments, the outer heat dissipation layer may comprise more than one layer of fine-array porous heat exchange materials, and may be configured such that the inner-most layer has the smallest pore size and each of the other layers has an increasing pore size compared with the layer disposed thereinside, in order to achieve an improved convection-mediated heat dissipation.

[0010] This disclosure also provides a heat sink system for cooling an electronic circuit, such as a CPU chip or a chip used in a variety of personal and cloud computing devices. The heat sink system substantially comprises a heat exchange apparatus, which thermally

contacts the electronic circuit to dissipate heat from the electronic circuit. The heat sink apparatus comprises a heat conduction layer and a heat dissipation layer, wherein the heat dissipation layer comprises substantially a layer of fine-array porous heat exchange material. In some embodiment, the heat sink system also includes a fan, wherein the fan is disposed on the heat exchange apparatus to further facilitate heat dissipation. In some embodiment, the heat sink system may comprise more than one layer of fine-array porous heat exchange materials, configured such that the inner-most layer that contacts the electronic circuit has the smallest pore size and each of the other layers has an increasing pore size compared with the layer disposed therebeneath, in order to achieve an improved convection-mediated heat dissipation.

[0011] A heat radiation system for warming ambient from a heat source is also disclosed herein, which substantially comprises a heat exchange apparatus, configured to thermally contact the heat source and to dissipate heat from the heat source to the ambient. The ambient can be air, a liquid like water, or an oil. The heat radiation apparatus comprises a heat conduction layer and a heat dissipation layer, wherein the heat dissipation layer comprises substantially a layer of fine-array porous heat exchange material as disclosed above. In some embodiment, the heat radiation system may comprise more than one layer of fine-array porous heat exchange materials, configured such that the inner-most layer that contacts the heat source has the smallest pore size and each of the other layers has an increasing pore size compared with the layer disposed therebeneath, in order to achieve an improved convection-mediated heat dissipation.

BRIEF DESCRIPTION OF THE DRAWINGS

- [0012]** FIG. 1 illustrates conventional heat sink apparatuses having cooling fins (A) or cooling pins (B).
- [0013]** FIG. 2 illustrates conventional heat sink apparatuses having designs for improved convection.
- [0014]** FIG. 3 illustrates a metal foam heat sink apparatus and the microstructure of the metal foam used as a heat sink material in the apparatus.
- [0015]** FIG. 4 illustrates a heat sink apparatus comprising a fine-array porous heat exchange material according to some embodiments of this disclosure.
- [0016]** FIG. 5 illustrates a heat sink apparatus comprising a double-layer fine-array porous heat dissipator.
- [0017]** FIG. 6 illustrates one type of heat exchanger tube comprising fine-array porous heat exchange materials according to some embodiments of this disclosure.

- [0018] FIG. 7 illustrates another type of heat exchanger tube 600 comprising fine-array porous heat exchange materials according to some embodiments of this disclosure.
- [0019] FIG. 8 illustrates a LED light bulb comprising a fine-array porous heat sink apparatus.
- [0020] FIG. 9 illustrates a CPU heat sink system 900 comprising a fine-array porous heat exchange materials according to some embodiments of this disclosure.
- [0021] FIG 10 illustrates a heat sink apparatus having fine-array porous heat exchange material according to some embodiment.

DETAILED DESCRIPTION THE DRAWINGS

- [0022] A heat exchange apparatus typically transfers heat from a heat source to a medium in the ambient, such as air, water, oil or a refrigerant. Some common heat exchange apparatuses may include a heat sink, typically used to cool a device such as an LED light source and a CPU processor, a condenser, typically used in an air conditioner and refrigerator to transfer heat, and a heat radiator, typically used to radiate heat from a heat source.
- [0023] FIG. 1 illustrates conventional heat sink apparatuses having cooling fins (A), or cooling pins (B). In a regular design, as illustrated in FIG. 1A, a conventional heat sink apparatus 100 may comprise a base 102 and an array of fins 103, wherein the base 102 is in touch with a heat source 101, the array of fins 103 is configured such that the array of fins vertically extend from the base 102 and are spaced apart with open gaps 104. By this configuration, this type of conventional heat sink apparatus 100 can effectively dissipate heat produced by the heat source 101 by conduction of and radiation from the array of fins 103, and by convection mediated by flow of air in the open gaps 104 between fins. In order to further increase the heat dissipating area of a conventional heat sink apparatus, fins are sometimes treated to have an undulating or serrated surface 105. In some variants, such as in the heat sink apparatus 110 illustrated in FIG. 1B, an array of pins 111 are used to replace the array of fins 103 in the heat sink apparatus 100 in FIG. 1A, which vertically extend from a base 112 and are spaced apart.
- [0024] FIG. 2 illustrates conventional heat sink apparatuses having designs for improved convection. In one design, as illustrated in FIG. 2A, a heat sink apparatus 200 may comprise a base 202 and an array of alternately placed long and short fins 203, wherein the base 202 is in touch with a heat source 201, the array of alternately placed long and short fins 203 is configured such that the fins vertically extend from the base 202 and are spaced apart with open gaps 204. In such a configuration, the array of alternately placed long and short fins

203 substantially form a more dense array at the base end 205 and a more loose array at the open end 206, essentially allowing a favorable formation of heat gradients from the base end 205 to the open end 206. Thereby a conventional heat sink apparatus with such improved design 200 can achieve more efficient convection cooling compared with a conventional heat sink apparatus with a regular design 100 (FIG. 1A). However, as a tradeoff, a heat sink apparatus with such a design 200 has a reduced surface area for heat dissipation mediated by conduction and radiation. In a similar design, as illustrated in FIG. 2B, a heat sink apparatus 210 may comprise an array of fins 211, wherein the array of fins 211 have a flared configuration to thereby achieve an efficient convection cooling. In yet another design, as illustrated in FIG. 2C, a heat sink apparatus 220 may comprise an array of flared pins 221 to also achieve an efficient convection cooling.

[0025] FIG. 3 illustrates a metal foam heat sink apparatus and the microstructure of the metal foam used as a heat sink material used in the apparatus. The metal foam heat sink apparatus 300 may include a heat conductive substrate 301 and a metal foam heat dissipator 302, wherein the heat conductive substrate 301 is in touch with a heat source 305, the metal foam heat dissipator 302 is disposed over and is in thermal contact with the heat conductive substrate 301, and the metal foam heat dissipator 302 substantially comprises a metal foam material. The metal foam material used in the metal foam heat dissipator 302 typically comprises an interconnected matrix of metallic ligaments 303 with varying lengths and orientations, and individual void spaces (pores) 304 of different shapes and sizes are formed between adjacent ligaments. Typical metal foams may have pore sizes of 0.5-8 mm, with a variation often higher than 100%. Compared with a conventional heat sink apparatus such as 100, 110, 200, 210 and 220 (FIGs. 1 and 2), a metal foam heat sink apparatus 300 typically achieves better conduction/radiation-mediated heat dissipation due to the much larger relative surface area of the metal foam heat dissipator 302. However, a metal foam heat sink apparatus 300 is usually less capable of achieving efficient convection-mediated heat dissipation due to the typically irregular shapes and sizes of the void spaces (pores) 304 formed in the metal foam heat dissipator 302.

[0026] FIG. 4A illustrates a heat sink apparatus comprising a fine-array porous heat exchange material according to some embodiments of this disclosure. The heat sink apparatus 400 comprise a heat conductor 401 and a heat dissipator 402, wherein the heat conductor 401 comprises a heat conductive material, the heat dissipator 402 comprises a fine-array porous heat exchange material, and the heat dissipator 402 is configured to dispose over and thermally contact with the heat conductor 401 such that the heat conductor 401 thermally transfers heat from a heat source 405 to the heat dissipator 402 for dissipation

into the air. The heat conductive material 402 used in the heat conductor 401 may be a metal, such as Cu, Ni, Fe, Al, Au, Ag, Ti or Fe, an alloy, such as an aluminum alloy, or a copper alloy, or a heat conductive composite metal/metal oxide, such as Ti/TiO₂ and Al/Al₂O₃. The fine-array porous heat exchange material used in the heat dissipator 402 may be made of the heat conductive material as used in the heat conductor 401 (please confirm), and may contain highly packed and substantially uniform pores 404, as shown in a 2D view 403. The pores can have sizes of, for example, about 10 μm – 1 cm, and preferably about 100 μm – 1 mm, and can have a porosity of 40 - 85%, preferably about 68-74%. The size of the pores in the fine-array porous heat exchange material is substantially uniform with a variation of less than about 20% and preferably of less than about 10%. In some embodiments, the fine-array porous heat exchange material can be a fine-array porous heat exchange membrane, having a thickness of 200 μm - 10 cm, and preferably of 500 μm - 1000 μm . The fine-array porous heat exchange material can have a surface area larger than 100 cm², such as 20 cm $\times$ 20 cm. Compared with a conventional heat sink apparatus such as 100, 110, 200, 210 and 220 (FIGs. 1 and 2) and a metal foam heat sink apparatus 300 (FIG. 3), a heat sink apparatus 400 as disclosed herein typically can achieve a much better conduction/radiation-mediated heat dissipation because of a much higher heat dissipating surface area due to the significantly higher surface-area-to-volume ratio of the fine-array porous heat exchange material used in the heat dissipator. It is estimated that a fine-array porous heat sink as disclosed herein can have a surface-area-to-volume ratio of 40-85%, whereas a conventional heat sink and a metal foam heat sink may have such a ratio ranging 5-15% and 15~30%, respectively. In addition, because of substantially uniform pores in the fine-array porous heat dissipator, flow of air within the pores can achieve a laminar flow, a feature substantially preventing local heat accumulation and allowing more efficient convection cooling of a fine-array porous heat sink apparatus compared with a metal foam heat sink apparatus. In some embodiment, as illustrated in FIG. 4B, a fine-array porous heat sink 410 may comprise two fine-array porous heat dissipators 412 disposed over and thermally contacting both surfaces of the heat conductor 411 to further increase the heat-dissipating surface area.

[0027] In some embodiments of the heat sink apparatus, the heat dissipator may comprise multiple layers of fine-array porous heat exchange material with different pore sizes. FIG. 5A illustrates a heat sink apparatus having a double-layer fine-array porous heat dissipator. This heat sink apparatus 500 comprises a heat conductor 501 and a heat dissipator 502, wherein the heat dissipator 502 is configured to dispose over and thermally contact the heat conductor 501 such that the heat conductor 501 thermally transfers heat from a heat source

505 to the heat dissipator 502 for dissipation into air. The heat dissipator 502 substantially comprises a first layer of fine-array porous heat exchange material 503 and a second layer of fine-array porous heat exchange material 504, configured such that the first layer of fine-array porous heat exchange material 503 has a smaller pore size and is in thermal contact with the heat conductive layer 501, and that the second layer of fine-array porous heat exchange material 504 is disposed over the first layer of fine-array porous heat exchange material 503 and has a larger pore size. In some embodiments, the ratio of pore sizes of the second layer 504 and the first layer 503 can be 2:1 - 1000:1, and the ratio of thickness of the second layer 504 and the first layer 503 can be 0.01:1 - 1000:1 depending on the pore sizes of the two layers. With this configuration, the double-layer fine-array porous heat sink apparatus 500, in addition to an efficient conduction/radiation-mediated heat dissipation due to the large relative surface area of the fine-array porous heat exchange material used in the heat dissipator, can achieve an improved convection-mediated heat dissipation due to the favorable establishment of a heat gradient along the direction of air flow within the pores from the first layer 503 to the second layer 504 of the heat dissipator 502. In some other embodiments, the fine-array porous heat sink apparatus may contain more than two layers of fine-array porous heat dissipator such that the first layer has the smallest pore size and is in thermal contact with the heat source, and that each of the other layers has an increasing pore size compared with the layer disposed therebeneath. In some embodiment, as illustrated in FIG 5B, a fine-array porous heat sink 510 may comprise two double-layer heat dissipators 512, disposed over and thermally contacting both surfaces of the heat conductor 511 to further increase the heat-dissipating surface area. Each of the double-layer heat dissipator 512 comprises a first layer of fine-array porous heat exchange material 513 and a second layer of fine-array porous heat exchange material 514, configured such that the first layer of fine-array porous heat exchange material 513 has a smaller pore size and is in thermal contact with the heat conductive layer 511, and that the second layer of fine-array porous heat exchange material 514 is disposed over the first layer of fine-array porous heat exchange material 513 and has a larger pore size. This configuration allows efficient heat dissipation by both increasing the heat-dissipating surface area of the heat sink apparatus 510.

[0028] The fine-array porous heat exchange materials and apparatuses disclosed above can have many practical applications.

[0029] FIG. 6 illustrates one type of heat exchanger tube 600 comprising fine-array porous heat exchange materials according to some embodiments of this disclosure, with their cross-sectional views shown. In one embodiment, as illustrated in FIG. 6A, the heat exchanger

tube 600 comprises an inner heat conduction tube 602 and an outer heat dissipation tube 603, wherein the inner heat conduction tube 602 comprises a heat conductive material, the outer heat dissipation tube 603 comprises a fine-array porous heat exchange material, and the outer heat dissipation tube 603 is disposed on and thermally contacts the outside face of the inner heat conduction tube 602 such that the inner heat conduction tube 602 transfers heat from a first medium 604 flowing through the inner heat conduction tube 602 to the outer heat dissipation tube 603 for dissipation into a second medium 605 outside the outer heat dissipation tube 603. The inner heat conduction tube 602 may have a thickness of 5 μm – 10 cm, and may comprise a metal, such as Cu, Ni, Fe, Al, etc, in some embodiments, or a heat conductive ceramics, such as AlN, Al_2O_3 in some other embodiments. The outer heat dissipation tube 603 may have a thickness of 0.5 μm – 1 cm, and the fine-array porous heat exchange material used for the outer heat dissipation tube 603 may be made of a metal, such as Cu, Ni, Fe or Al in some embodiments, or a heat conductive ceramics/polymers in some other embodiments. The fine-array porous heat exchange material used in the outer heat dissipation tube 603 has technical parameters similar to that in the fine-array porous heat sink apparatus 400 shown in FIG. 4. In some embodiments, the outer heat dissipation tube 603 may comprise more than one layer of fine-array porous heat exchange materials. In one such embodiment illustrated in FIG. 6B, the outer heat dissipator tube comprises a first layer of fine-array porous heat exchange material 613 and a second layer of fine-array porous heat exchange material 614, wherein the first layer of fine-array porous heat exchange material 613 has a smaller pore size and is disposed on the outside face of the inner heat conductor tube 612, and the second layer of fine-array porous heat exchange material 614 has a larger pore size and is disposed on the outside face of the first layer of fine-array porous heat exchange material 613. This configuration can achieve an improved convection-mediated heat dissipation in a mechanism similar to the heat sink apparatus 500 as disclosed in FIG. 5A.

[0030] FIG. 7 illustrates another type of heat exchanger tube 700 comprising fine-array porous heat exchange materials according to some embodiments of this disclosure, with cross-sectional views shown. In one embodiment, as illustrated in FIG. 7A, the heat exchanger tube 700 comprises an inner heat dissipation tube 702 and an outer heat conduction tube 703, wherein the inner heat dissipation tube 702 comprises a fine-array porous heat exchange material, the outer heat conduction tube 703 comprises a heat conductive material, and the outer heat conduction tube 703 is disposed on and thermally contacts the outside face of the inner heat dissipation tube 702 such that the outer heat conduction tube 703 transfers heat from a first medium 705 outside the outer heat

conduction tube 703 to the inner heat dissipation tube 702 for dissipation into a second medium 704 flowing through the inner heat dissipation tube 702. The outer heat conduction tube 703 may have a thickness of 5 μm – 10 cm, and may comprise a metal, such as Cu, Ni, Fe, Al, etc, in some embodiments, or a heat conductive ceramics/polymers, such as AlN and Al_2O_3 in some other embodiments. The inner heat dissipation tube 702 may have a thickness of 0.5 μm – 1 cm, and the fine-array porous heat exchange material used for the inner heat dissipation tube 702 may be made of a metal, such as Cu, Ni, Fe or Al in some embodiments, or a heat conductive ceramics/polymers in some other embodiments. The fine-array porous heat exchange materials used in the inner heat dissipation tube 702 have technical parameters similar to that in the fine-array porous heat sink apparatus 400 shown in FIG. 4. In some embodiments, the inner heat dissipation tube 702 may comprise more than one layer of fine-array porous heat exchange materials. In another embodiment illustrated in FIG. 7B, the heat exchange tube 710 comprises an outer heat conduction tube 713, a first layer of fine-array porous heat exchange material 712, and a second layer of fine-array porous heat exchange material 714, wherein the first layer of fine-array porous heat exchange material 712 has a smaller pore size and is disposed on and thermally contacts the inside face of the heat conductor tube 713, the second layer of fine-array porous heat exchange material 714 has a larger pore size and is disposed on the inside face of the first layer of fine-array porous heat exchange material 712. This configuration can achieve an improved convection-mediated transfer of heat from outside medium to the inside medium, in a mechanism similar to the heat sink apparatus 500 as disclosed in FIG. 5A.

[0031] FIG. 8 illustrates a LED light bulb 800 comprising a fine-array porous heat sink apparatus, with its cross-section view of the heat sink 810 shown. The LED light bulb 800 comprises a bulb body 801 and a bulb housing 802, wherein the bulb housing 802 encloses and thermally contacts the bulb body 801. The bulb housing 802 comprising an inner heat conduction layer 812 and an outer heat dissipation layer 811, wherein the inner heat conduction layer 812 comprises a heat conductive material and the outer heat dissipation layer 811 comprises substantially a fine-array porous heat exchange material and the outer heat dissipation layer 811 is disposed on and thermally contacts the outside face of the inner heat conduction layer 812 such that the inner heat conduction layer 812 transfers heat from the LED light bulb to the outer heat dissipation layer 811 for dissipation into the air. In some embodiments, the outer heat dissipation layer 802 may comprise more than one layer of fine-array porous heat exchange materials, configured in a manner similar to the heat exchanger tube 610 disclosed in FIG. 6, in order to achieve an improved convection-

mediated heat dissipation, facilitated by the favorable establishment of a heat gradient across the different layers of the fine-array porous heat exchange materials.

[0032] A heat sink comprising fine-array porous heat exchange materials may be applied in a variety of personal and cloud computing devices to provide effective and efficient cooling to electronic circuits contained therein. FIG. 9 illustrates a CPU heat sink system 900 comprising fine-array porous heat exchange materials according to some embodiments of this disclosure. In one embodiment, as illustrated in FIG. 9A, the CPU heat sink system 900 comprises a heat sink apparatus 903 and a fan 904, wherein the heat sink apparatus 903 is sandwiched between and thermally contacts a CPU chip 902, mounted on a substrate 901, and the fan 904 such that heat released from the CPU chip 902 is transferred to the heat sink apparatus 903, and is dissipated in the air facilitated by the fan 904. The heat sink apparatus 903 comprises a heat conduction layer 905, having a thickness of 1 μm - 1000 μm , and a heat dissipation layer 906, having a thickness of 500 μm - 10 cm, wherein the heat conduction layer 905 comprises a heat conductive material, the heat dissipation layer 906 comprises a layer of fine-array porous heat exchange material. The fine-array porous heat exchange material may have a pore size of about 10 μm - 1 cm, preferably about 100 μm - 1 mm, and may have a porosity of 40 - 85%, preferably about 68-74%. The size of the pores in the fine-array porous heat exchange material is substantially uniform with a variation of less than about 20% and preferably of less than about 10%. In another embodiment, as illustrated in FIG. 9B, the CPU heat sink system 910 has a similar configuration with the CPU heat sink system 900, having a heat sink apparatus 913 disposed between a CPU chip 912 and a fan 914. Besides a heat conduction layer 915, the heat sink apparatus 913 also comprises a double-layer heat dissipation layer 916, wherein the double-layer heat dissipation layer 916 comprises two layers of fine-array porous heat exchange materials, with a top layer 917 contacting the fan 914 and having a larger pore size, and a bottom layer 918 contacting the heat conduction layer 915 and having a smaller pore size. In some embodiments of a CPU heat sink system, the heat dissipation layer of the heat sink apparatus may comprise more than two layers of fine-array porous heat exchange materials, having an increasing pore size across the different layers of fine-array porous heat exchange materials along the direction from the heat conduction layer-contacting surface to the fan-contacting surface. In addition to CPU heat sink systems, a heat sink comprising fine-array porous heat exchange materials may be employed to effectively cool a cloud computing device, such as cloud servers and cloud data centers.

[0033] In some embodiments, a fine-array porous heat exchange material may be used on the outer surface of fins or pins in conventional designs of heat sinks, to further increase the

heat dissipating surface area for improved heat exchange. FIG. 10 illustrates a heat sink apparatus having fine-array porous heat exchange material according to some embodiment. The heat sink apparatus 1000 has substantially a similar basic structure as in the conventional heatsink 200 as illustrated in FIG. 2A, comprising a base 1002 and an array of alternately placed long and short fins 1003, wherein the base 1002 is in thermal touch with a heat source 1001, the array of alternately placed long and short fins 1003 is configured such that the fins vertically extend from the base 1002 and are spaced apart with open gaps 1004. Similar to the heat sink 200, the array of alternately placed long and short fins 1003 in the heat sink 1000 also form a more dense array at the base end 1005 and a more loose array at the open end 1006, allowing a favorable formation of heat gradients from the base end 1005 to the open end 1006 to thereby achieve an efficient convection cooling. A unique feature of the heat sink apparatus 1000 is that each of the array of alternately placed long and short fins 1003 comprises a heat conductive fin body 1007 and a layer of fine-array porous heat exchange material 1008 disposed over and thermally contacting the heat conductive fin body 1007, allowing each of the fins 1003 to essentially form a heat sink as shown in FIG. 3. With this configuration, in addition to having a large heat-dissipating surface area, the heat sink 1000 can also achieve an efficient convection cooling both locally on each of the fins 1003, and on the whole structure of the heat sink 1000. In some embodiments, the heat sink 1000 may have another layer of fine-array porous heat exchange material, disposed on the outside of the layer of fine-array porous heat exchange material 1008 and having a larger pore size. In some other embodiments, the heat sink apparatus 1000 may comprises more than two layers of fine-array porous heat exchange materials disposed over and thermally contacting the heat conductive fin body 1007, having an increasing pore size across the different layers of fine-array porous heat exchange materials along the inner-most to the outer-most direction.

[0034] Although specific embodiments have been described above in detail, the description is merely for purposes of illustration. It should be appreciated, therefore, that many aspects described above are not intended as required or essential elements unless explicitly stated otherwise. Various modifications of, and equivalent acts corresponding to, the disclosed aspects of the exemplary embodiments, in addition to those described above, can be made by a person of ordinary skill in the art, having the benefit of the present disclosure, without departing from the spirit and scope of the disclosure defined in the following claims, the scope of which is to be accorded the broadest interpretation so as to encompass such modifications and equivalent structures.

Claims

1. A heat exchange material for use in a heat exchange apparatus, comprising a fine-array porous material, wherein:
 - the fine-array porous material comprises a metal, an alloy, or a metal/metal oxide composite;
 - the fine-array porous material comprises a plurality of pores, wherein the plurality of pores have a size of less than about 5000 μm ;
 - the size of the plurality of pores is substantially uniform with a variation of less than about 20%; and
 - the fine-array porous material has a porosity of about 40-85%.
2. The heat exchange material according to Claim 1, wherein the fine-array porous material has a porosity of about 74%.
3. The heat exchange material according to Claim 1, wherein the fine-array porous material comprises a metal, selected from a group consisting of Ni, Al, Cu, Au, Ag, Ti, and Fe.
4. The heat exchange material according to Claim 3, wherein the fine-array porous material comprises Cu.
5. The heat exchange material according to Claim 1, wherein the fine-array porous material comprises an alloy, selected from a group consisting of an aluminum alloy, a copper alloy, and a nickel alloy.
6. The heat exchange material according to Claim 5, wherein the fine-array porous material comprises an aluminum alloy.
7. A heat exchange apparatus, comprising at least one heat dissipation layer, wherein each of the at least one heat dissipation layer comprises the heat exchange material according to Claim 1.
8. The heat exchange apparatus of Claim 7, further comprising a heat conduction layer, wherein:
 - the heat conduction layer comprises a heat conductive material;
 - the heat conduction layer is disposed on and thermally contacts the at least one heat dissipation layer to thereby thermally transfer heat from a higher temperature medium in contact with the heat conduction layer to a lower temperature medium in contact with the at least one heat dissipation layer.
9. The heat exchange apparatus of Claim 8, comprising one heat dissipation layer.

10. The heat exchange apparatus of Claim 8, comprising two heat dissipation layers, wherein the two heat dissipation layers consists of a first heat dissipation layer and a second heat dissipation layer, wherein:

the first heat dissipation layer is disposed on and thermally contacts with the heat conduction layer; and

the second heat dissipation layer has a larger pore size than the first heat dissipation layer and is disposed over the first heat dissipation layer.

11. The heat exchange apparatus of Claim 10, wherein:

the second heat dissipation layer and the first heat dissipation layer has a pore size ratio of about 2:1 - 1000:1;

the second heat dissipation layer and the first heat dissipation layer has a thickness ratio of about 0.01:1 - 1000:1, the ratio depending on pore size of the first heat dissipation layer and pore size of the second heat dissipation layer.

12. The heat exchange apparatus of Claim 7, further comprising a heat sink main body, wherein:

the heat sink main body comprises a base and an array of extrusions, wherein the array of extrusions are configured to extend from the base and are spaced apart with open gaps; and

the at least one heat dissipation layer is coated on the heat sink main body.

13. The heat exchange apparatus of Claim 12, wherein the array of extrusions are an array of fins.

14. The heat exchange apparatus of Claim 13, wherein the array of fins comprises an array of alternately placed long and short fins.

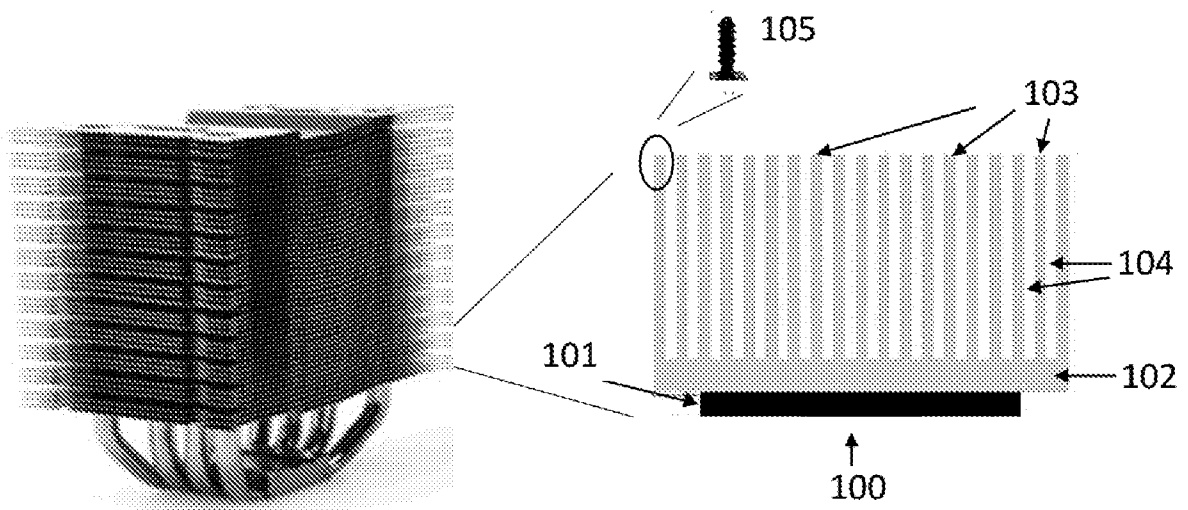
15. The heat exchange apparatus of Claim 13, wherein the array of fins have a flared configuration.

16. The heat exchange apparatus of Claim 12, wherein the array of extrusions are an array of pins.

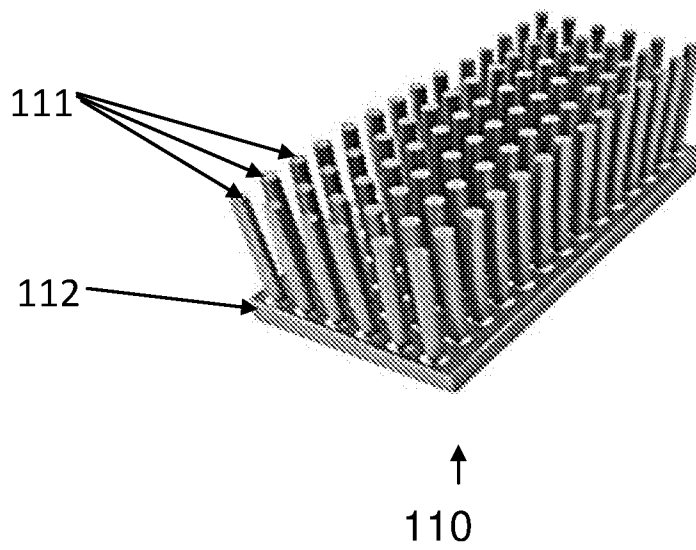
17. The heat exchange apparatus of Claim 16, wherein the array of pins have a flared configuration.

18. The heat exchange apparatus of Claim 8, wherein the heat conduction layer and the at least one heat dissipation layer take a form of an enclosed tube.

19. The heat exchange apparatus of Claim 18, wherein:
 - the heat conduction layer is disposed on an inside face of the heat exchange apparatus; and
 - the at least one heat dissipation layer is disposed on an outside face of the heat exchange apparatus to thereby thermally transfer heat from the higher temperature medium inside the heat exchange apparatus to the lower temperature medium outside the heat exchange apparatus.
20. The heat exchange apparatus of Claim 18, wherein:
 - the heat conduction layer is disposed on an outside face of the heat exchange apparatus; and
 - the at least one heat dissipation layer is disposed on an inside face of the heat exchange apparatus to thereby thermally transfer heat from the higher temperature medium outside the heat exchange apparatus to the lower temperature medium inside the heat exchange apparatus.
21. A heat sink system for cooling a LED light source in a LED light assembly, comprising a heat exchange apparatus according to Claim 7, wherein the heat exchange apparatus provides a housing for and thermally contacts the LED light source to dissipate heat from the LED light source.
22. A heat sink system for cooling an electronic circuit, comprising a heat exchange apparatus according to Claim 7, wherein a first side of the heat exchange apparatus thermally contacts the electronic circuit to dissipate heat from the electronic circuit.
23. The heat sink system according to Claim 22, further comprising a fan, wherein the fan is disposed on a second side of the heat exchange apparatus to further facilitate heat dissipation.
24. The heat sink system according to Claim 22, wherein the electronic circuit is a CPU chip.
25. The heat sink system according to Claim 22, wherein the electronic circuit is a chip in a cloud computing device.
26. A heat radiation system for warming ambient from a heat source, comprising a heat exchange apparatus according to Claim 7, wherein the heat exchange apparatus is configured to thermally contact the heat source and to dissipate heat from the heat source to the ambient.
27. The heat exchange material according to Claim 1, wherein the fine-array porous material comprises a metal/metal oxide composite, selected from a group consisting of Ti/TiO₂ and Al/Al₂O₃.



A



B

FIG. 1 (Prior Art)

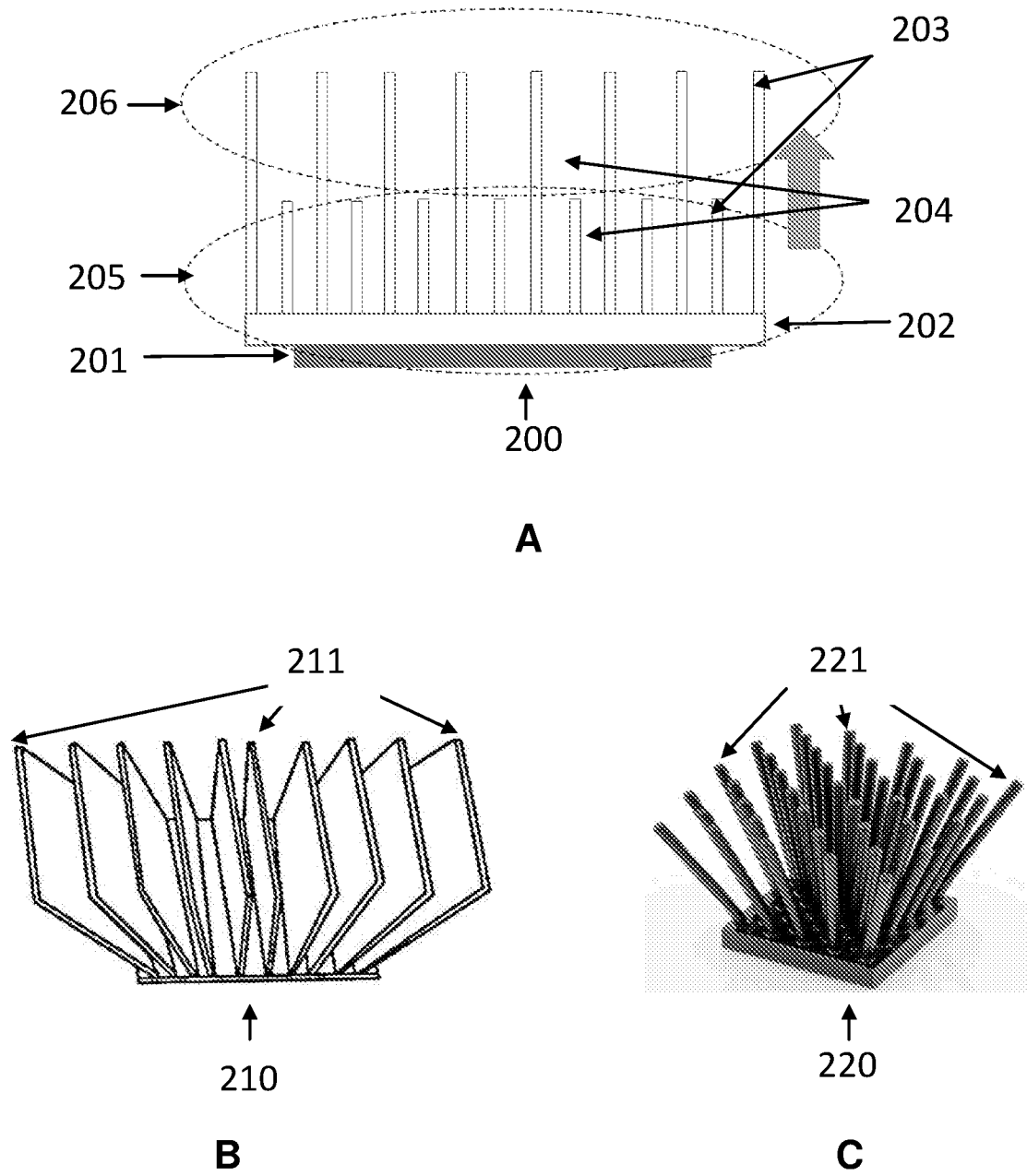


FIG. 2 (Prior Art)

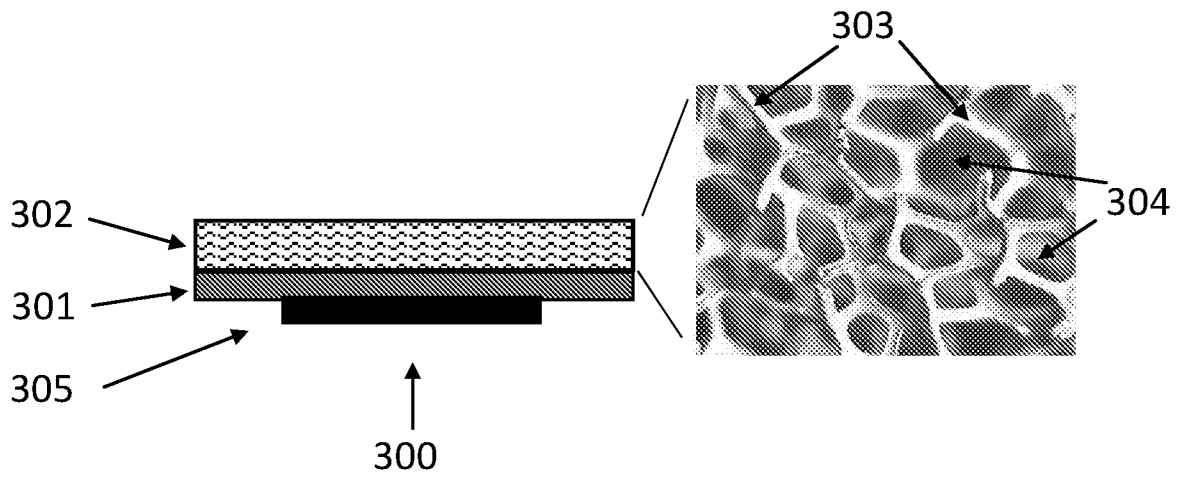
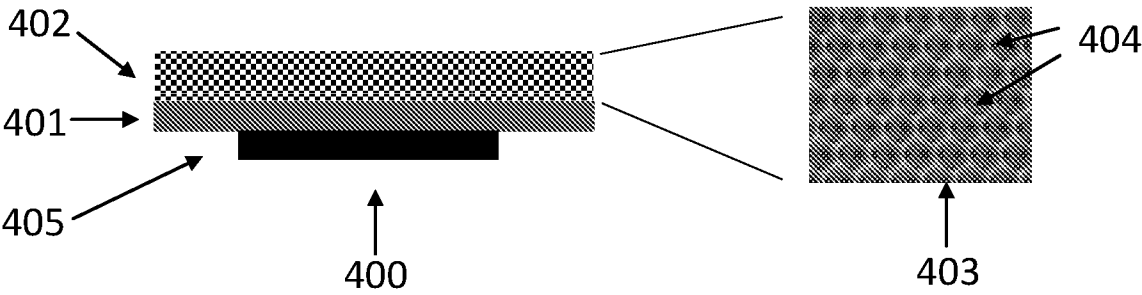
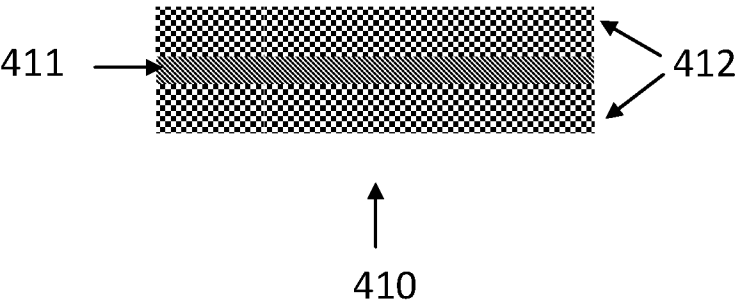


FIG. 3 (Prior Art)

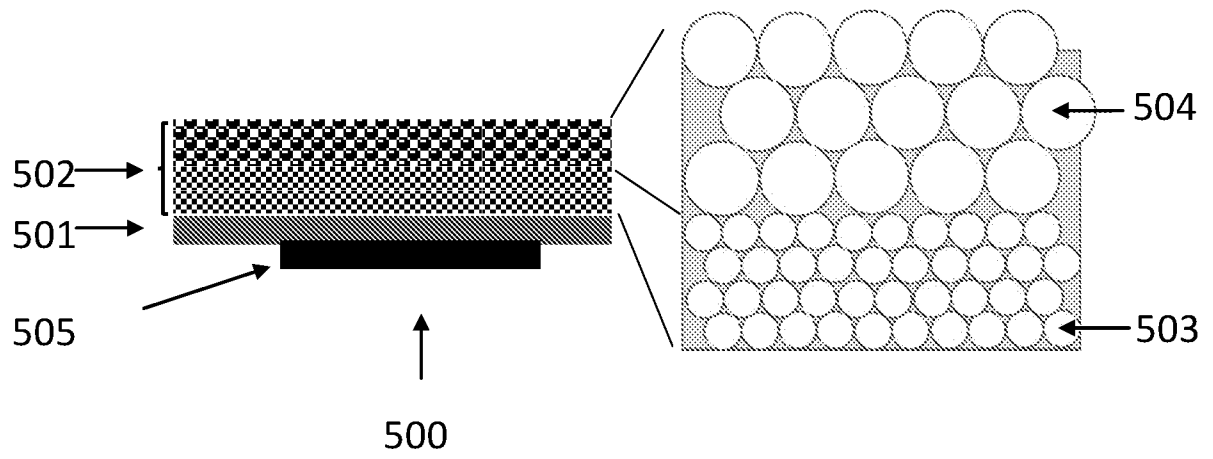


A

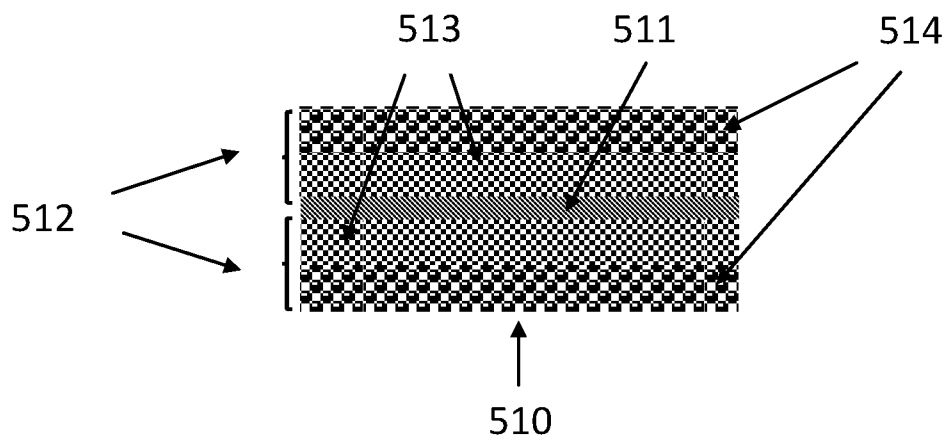


B

FIG. 4



A



B

FIG. 5

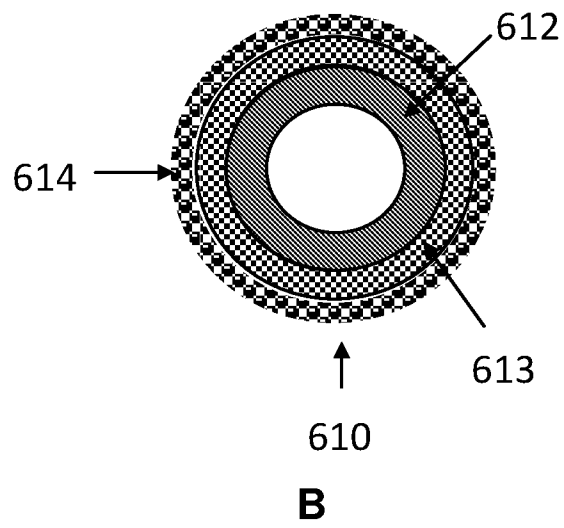
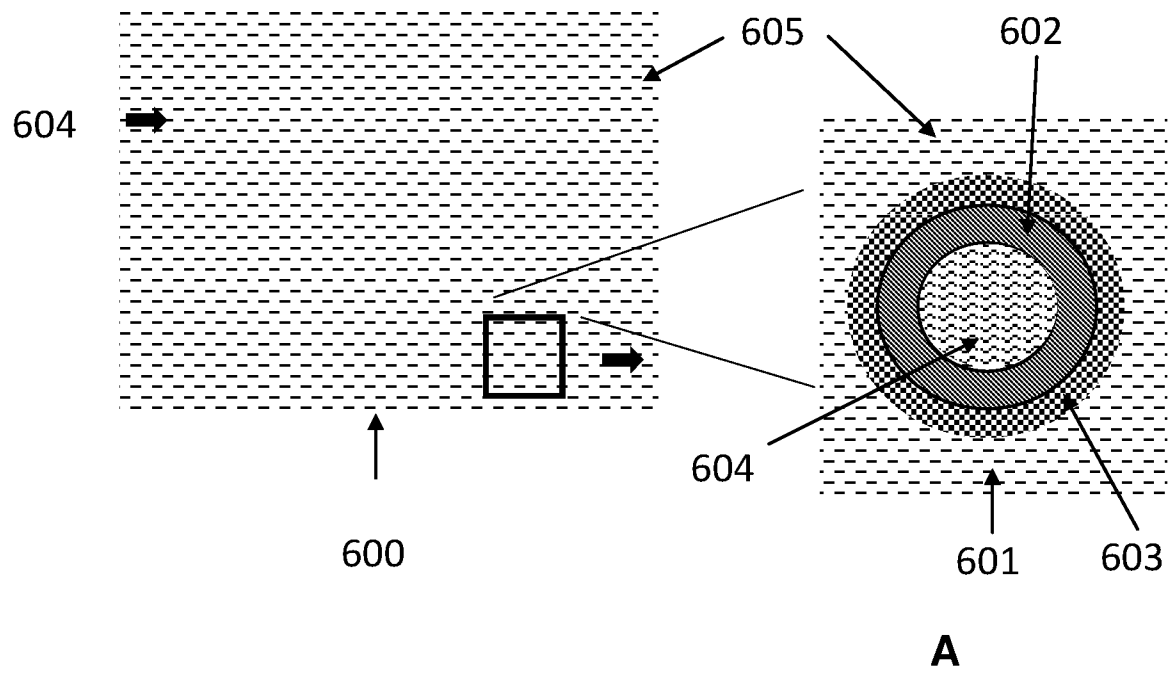
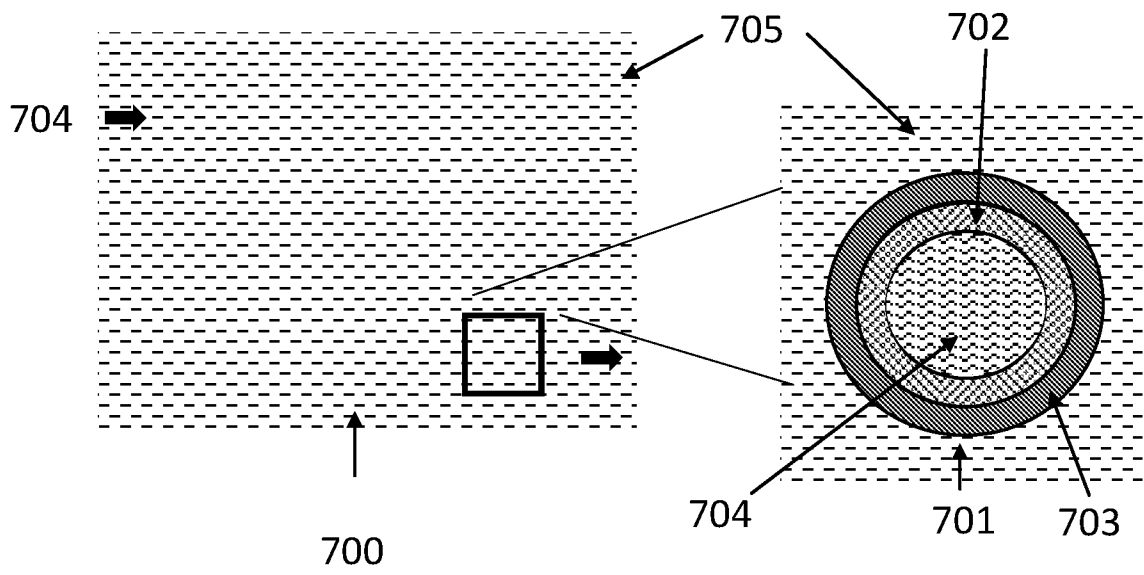
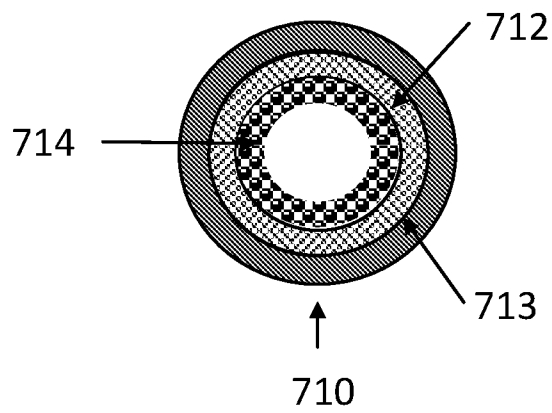


FIG. 6



A



B

FIG. 7

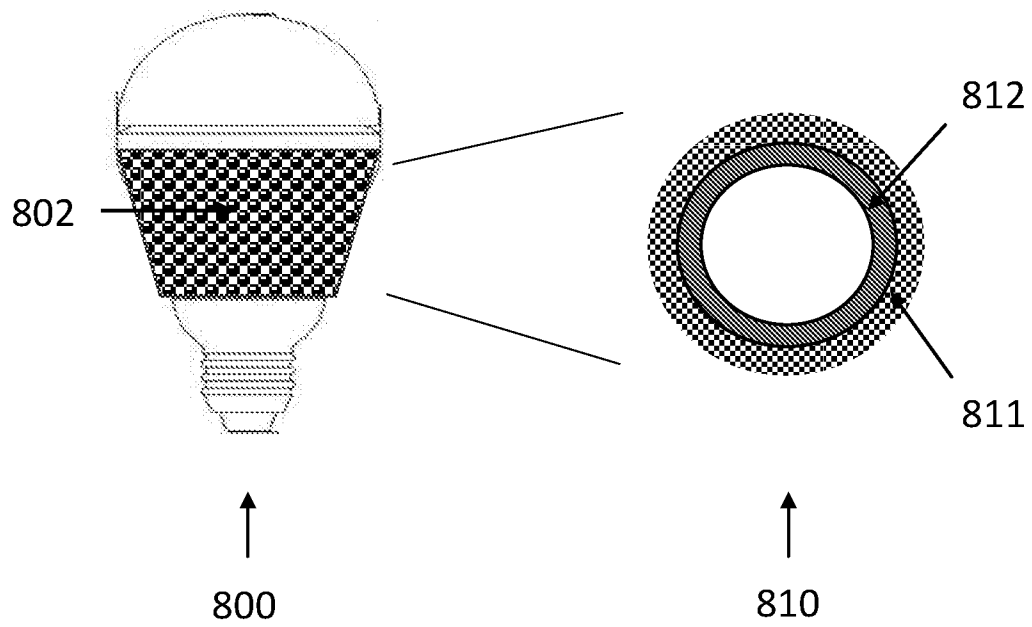


FIG. 8

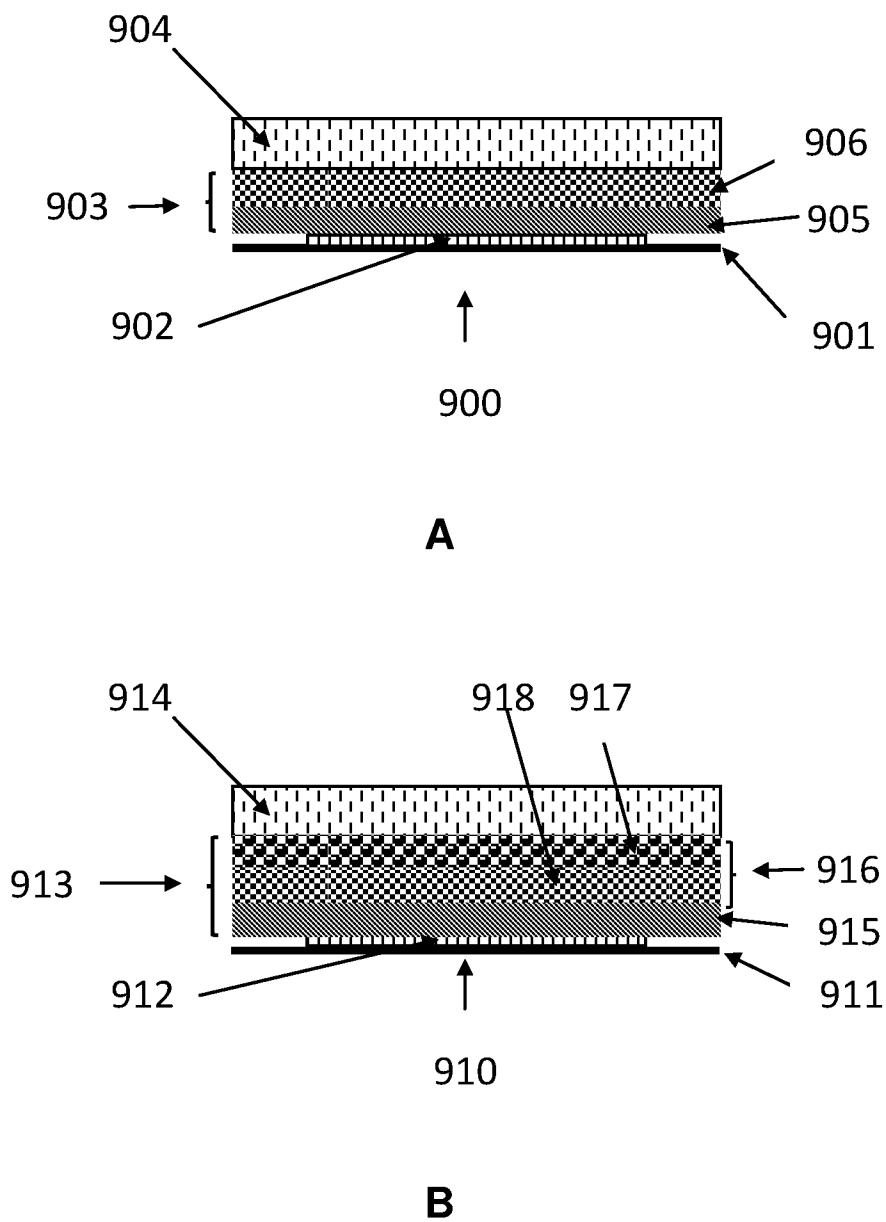


FIG. 9

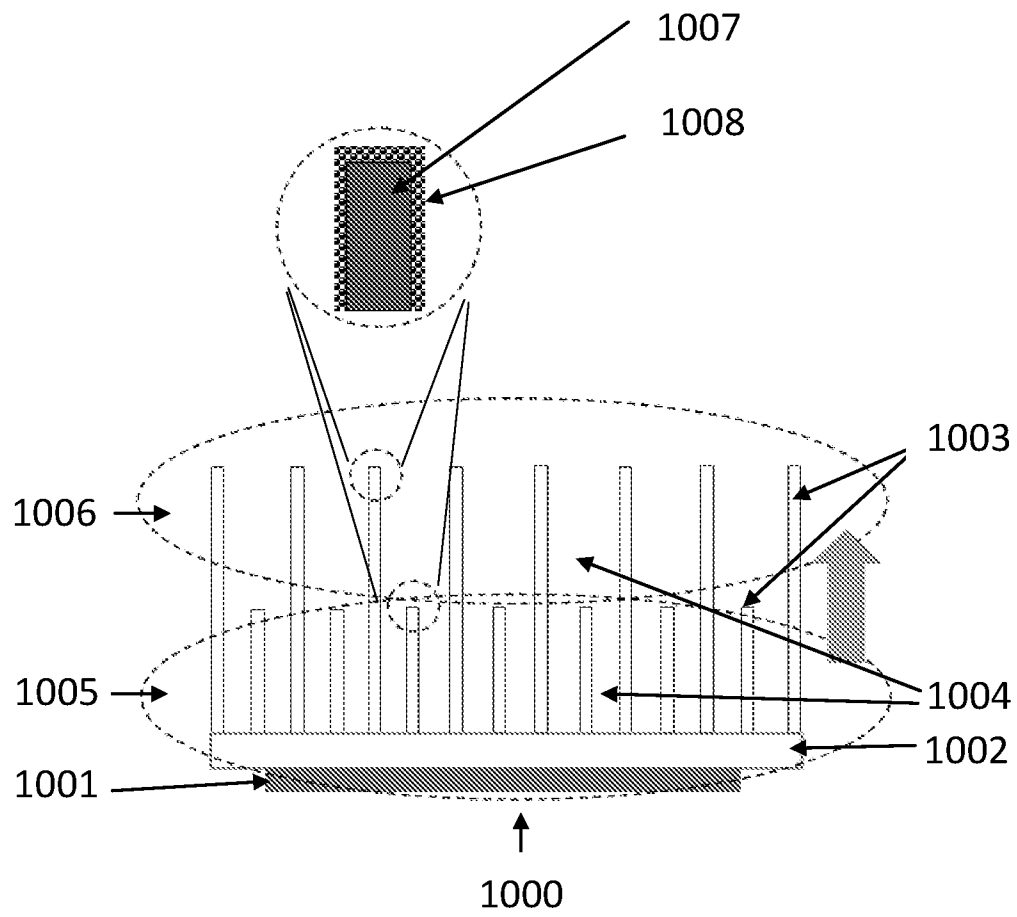


FIG. 10

INTERNATIONAL SEARCH REPORT

International application No.

PCT/CN2015/098937

A. CLASSIFICATION OF SUBJECT MATTER		
F28F 1/10(2006.01)i		
According to International Patent Classification (IPC) or to both national classification and IPC		
B. FIELDS SEARCHED		
Minimum documentation searched (classification system followed by classification symbols)		
F28F; F28D		
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched		
Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)		
CNKI, CPRS, WPI, EPODOC: porous, capillary, pore?, metal, foam, uniform??, single, regular+, average???, equal+, even		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2014182808 A1 (KOOKMIN UNIVERSITY LNDUSTRY ACADEMY COOPERATION FOUNDATION) 03 July 2014 (2014-07-03) description, paragraphs [0006]-[0068], figures 1 and 2	1-6
Y	US 2014182808 A1 (KOOKMIN UNIVERSITY LNDUSTRY ACADEMY COOPERATION FOUNDATION) 03 July 2014 (2014-07-03) description, paragraphs [0006]-[0068], figures 1 and 2	7-27
Y	KR 20080032324 A (JUNG UEE SOO) 15 April 2008 (2008-04-15) EPODOC abstract, figure 2	7-27
Y	KR 20110132198 A (LEE OUG KI) 07 December 2011 (2011-12-07) WPI abstract, figures 6-9	7-27
Y	CN 203672209 U (UNIV XIAMEN) 25 June 2014 (2014-06-25) description, paragraphs [0030]-[0034], figures 2-5	7-27
Y	CN 1053119 A (UNIV TIANJIN) 17 July 1991 (1991-07-17) claims 1-7	7-27
Y	GB 1392762 A (UNIVERSAL OIL PROD CO) 30 April 1975 (1975-04-30) claims 1-9, figures 1-5	12-17
☒ Further documents are listed in the continuation of Box C. ☒ See patent family annex.		
* Special categories of cited documents: "A" document defining the general state of the art which is not considered to be of particular relevance "E" earlier application or patent but published on or after the international filing date "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "O" document referring to an oral disclosure, use, exhibition or other means "P" document published prior to the international filing date but later than the priority date claimed "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art "&" document member of the same patent family		
Date of the actual completion of the international search		Date of mailing of the international search report
22 April 2016		27 September 2016
Name and mailing address of the ISA/CN		Authorized officer
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Facsimile No. (86-10)62019451		Telephone No. (86-10)62084192

INTERNATIONAL SEARCH REPORT

International application No.

PCT/CN2015/098937**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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A	KR 20070105223 A (KIM BYEONG CHANG) 30 October 2007 (2007-10-30) the whole document	1-27

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.

PCT/CN2015/098937

Patent document cited in search report			Publication date (day/month/year)	Patent family member(s)			Publication date (day/month/year)
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				FR	2152713	A1	27 April 1973
				FR	2152713	B1	12 September 1975
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				AU	461672	B2	05 June 1975
				IL	40244	A	15 October 1975
TW	M496090	U	21 February 2015	None			
KR	20070105223	A	30 October 2007	KR	100791854	B1	07 January 2008