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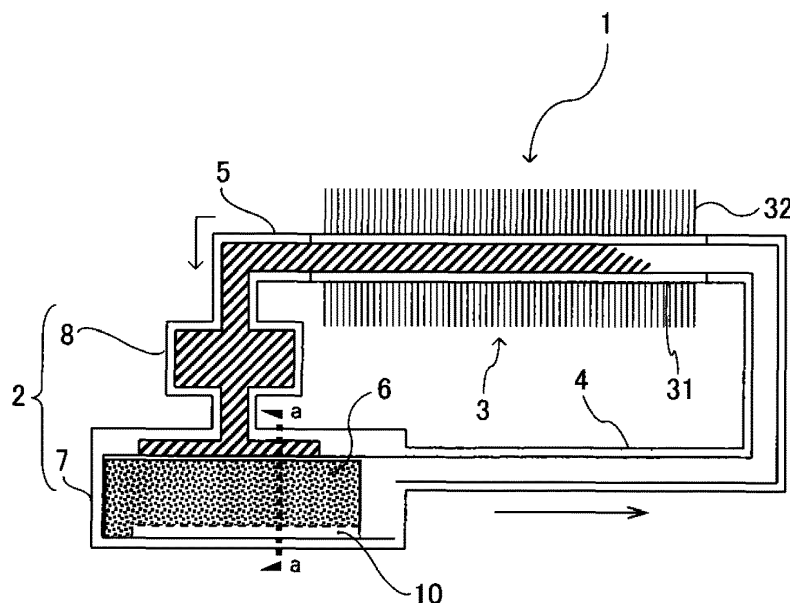
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(54) **WICK, EVAPORATOR, LOOP HEAT PIPE, COOLING DEVICE, ELECTRONIC DEVICE, AND METHOD OF MANUFACTURING WICK**

(57) A wick (6) disposed in an evaporator for changing a working fluid from liquid phase to gas phase, the wick (6) includes a porous medium the working fluid in liquid phase permeates, wherein oxygen has the largest

proportion among carbon, silicon, and oxygen in an elemental composition at a surface of a void of the porous medium.

FIG. 1



Description

BACKGROUND

5 Technical Field

[0001] The present disclosure relates to a wick disposed in an evaporator, an evaporator, a loop heat pipe, a cooling device, an electronic device, and a method of manufacturing a wick.

10 Description of the Related Art

[0002] A porous elastic wick a working fluid in liquid phase permeates is prevalent. The porous elastic wick is disposed inside an evaporator for changing a working fluid from liquid phase to gas phase.

15 **[0003]** Foamed silicone rubber as a porous elastic body has been proposed as the wick in Japanese Unexamined Patent Application Publication No. 2020-020495. Water is used as working fluid in Japanese Unexamined Patent Application Publication No. 2020-020495 mentioned above.

[0004] However, evaporators need improvement regarding cooling efficiency when water or hydrophilic fluid is used as working fluid.

20 SUMMARY

[0005] According to embodiments of the present disclosure, the cooling efficiency of an evaporator is enhanced.

25 **[0006]** According to embodiments of the present disclosure, provided is a wick (6) disposed in an evaporator for changing a working fluid from liquid phase to gas phase, the wick (6) including a porous medium the working fluid in liquid phase permeates, wherein oxygen has the largest proportion among carbon, silicon, and oxygen in the elemental composition at the surface of a void of the porous medium.

30 **[0007]** As another aspect of embodiments of the present disclosure, provided is a method of manufacturing a wick that is disposed in an evaporator for changing a working fluid from liquid phase to gas phase and includes a porous medium the working fluid in the liquid phase permeates, the method including subjecting the porous medium to treatment of making oxygen have the largest proportion among carbon, silicon, and oxygen in the elemental composition at the surface of a void of the porous medium.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

35 **[0008]** Various other objects, features and attendant advantages of the present invention will be more fully appreciated as the same becomes better understood from the detailed description when considered in connection with the accompanying drawings in which like reference characters designate like corresponding parts throughout and wherein:

40 FIG. 1 is a schematic diagram illustrating an example of the loop heat pipe according to an embodiment of the present disclosure;

FIG. 2 is a diagram illustrating an imaginary cross section of the loop heat pipe illustrated in FIG. 1 when cut along the dotted line a-a in FIG. 1;

FIG. 3 is a schematic diagram illustrating a typical loop heat pipe;

45 FIG. 4 is a schematic diagram illustrating another example of the loop heat pipe equipped in the electronic device relating to an embodiment of the present disclosure;

FIG. 5 is a table showing the specifications of samples and the test results of Examples and Comparative Examples;

FIG. 6 is a photo of a sample of the wick in void state in Example 1, which is described later, when the sample is observed with a laser microscope;

FIG. 7 is a graph illustrating an example of the void diameter distribution;

50 FIG. 8 is a photo of a sample of the wick of Example 1, which is described later, when the sample is observed with a scanning electronic microscope; and

55 FIG. 9 is a graph showing the proportion of silicon to carbon to oxygen when the elements at the surface of a representative sample of the wick for use in Example 1, which is described later, is analyzed by X-ray photoelectron spectroscopy (XPS). The accompanying drawings are intended to depict example embodiments of the present invention and should not be interpreted to limit the scope thereof. The accompanying drawings are not to be considered as drawn to scale unless explicitly noted. Also, identical or similar reference numerals designate identical or similar components throughout the several views.

DESCRIPTION OF THE EMBODIMENTS

[0009] In describing embodiments illustrated in the drawings, specific terminology is employed for the sake of clarity. However, the disclosure of this specification is not intended to be limited to the specific terminology so selected and it is to be understood that each specific element includes all technical equivalents that have a similar function, operate in a similar manner, and achieve a similar result.

[0010] As used herein, the singular forms "a", "an", and "the" are intended to include the plural forms as well, unless the context clearly indicates otherwise.

[0011] Moreover, image forming, recording, printing, modeling, etc., in the present disclosure represent the same meaning, unless otherwise specified.

[0012] Embodiments of the present invention are described in detail below with reference to accompanying drawing(s). In describing embodiments illustrated in the drawing(s), specific terminology is employed for the sake of clarity. However, the disclosure of this patent specification is not intended to be limited to the specific terminology so selected, and it is to be understood that each specific element includes all technical equivalents that have a similar function, operate in a similar manner, and achieve a similar result.

[0013] For the sake of simplicity, the same reference number will be given to identical constituent elements such as parts and materials having the same functions and redundant descriptions thereof omitted unless otherwise stated.

[0014] One embodiment of the loop heat pipe (hereinafter referred to as loop heat pipe 1) is described with reference to accompanying drawings. The loop heat pipe includes an evaporator and a condenser as a cooling device, the evaporator including the wick of the present disclosure inside.

[0015] In each drawing for describing the present embodiment, the same reference numeral is assigned to the elements such as the members or components having the same function or form. The description of the elements with the same number once described is occasionally omitted.

[0016] FIG. 1 is a schematic diagram illustrating the loop heat pipe 1 relating to the present embodiment. FIG. 2 is an imaginary cross sectional surface cut along the dotted line a-a illustrated in FIG. 1.

[0017] A working fluid composed of condensable fluid is encapsulated in the loop heat pipe 1 illustrated in FIG. 1. It includes an evaporating unit (evaporator) 2 for changing the working fluid from liquid phase to gas phase by absorbing heat from a heating unit and a condensing unit 3 for condensing the working fluid in gas phase guided from the evaporating unit 2 into liquid phase. It also includes a vapor tube 4 for sending the working fluid in gas phase from the evaporating unit 2 to the condensing unit 3 and a liquid tube 5 for sending the working fluid in liquid phase from the condensing unit 3 to the evaporating unit 2.

[0018] The evaporating unit 2 includes a heat receiving unit 7 accommodating a wick 6 inside and a reserver 8 storing the working fluid in liquid phase.

[0019] One end of the vapor tube 4 is linked with the heat receiving unit 7. One end of the liquid tube 5 is linked with the reserver 8. The respective other ends of the vapor tube 4 and the liquid tube 5 are linked with the condensing unit 3. The condensing unit 3 includes stainless pipe 31 and multiple thin plate-like aluminum fins 32 are disposed on the outer surface of the stainless pipe 31.

[0020] The wick 6 is a porous medium. Multiple grooves 10 are provided to the bottom of the wick 6 in FIG. 1 across the end on the side of the vapor tube 4 towards the opposite side.

[0021] The multiple grooves 10 are provided on the bottom of the wick 6 spaced equally therebetween as in FIG. 2, which illustrates an imaginary cross section obtained when cut along with the dotted line a-a in FIG. 1. In FIG. 2, the grooves 10 are illustrated in a larger scale than real. The thickness of the wick 6 has a little larger dimension than the inside dimension of the housing of the heat receiving unit 7 of the evaporating unit 2.

[0022] Owing to these settings of the thickness of the wick 6, the wick 6 is attached to the inside surface of the heat receiving unit 7 when the wick 6 is accommodated in the heat receiving unit 7. The heat of the heating unit is efficiently transferred to the wick 6 through the housing of the heat receiving unit 7 when the wick 6 is attached to the heat receiving unit 7. On the other hand, space is formed between the portions where the grooves 10 are provided and the housing of the heat receiving unit 7.

[0023] The wick 6 is a porous medium, i.e., made of porous material so that the working fluid in liquid phase which is stored in the reserver 8 permeates the wick 6 due to capillary action. Owing to this capillary action, the wick 6 serves as a pump for sending the working fluid in liquid phase from the condensing unit 3 to the evaporating unit 2.

[0024] Condensable fluid such as water, alcohol, acetone, and alternative CFCs are used as the working fluid. Water, which has high latent heat, is preferably used as the working fluid to achieve good cooling ability. Moreover, the working fluid having a good wettability with the wick 6 is preferable in order to permeate the wick 6. The wettability can be determined by the contact angle between the wick 6 and the working fluid. The contact angle should be less than 40 degrees because the working fluid cannot permeate the wick 6 with a contact angle of 40 degrees or greater. A contact angle less than 10 degrees is more preferable because capillary action is more efficient,

[0025] In the loop heat pipe 1 relating to the present embodiment, the working fluid in liquid phase evaporates and

changes into gas phase owing to the heat from the heating unit transferred to the working fluid in liquid phase in the wick 6 via the housing of the evaporating unit 2 (heat receiving unit 7). The working fluid changed from liquid phase to gas phase is sent to the vapor tube 4 via the grooves 10. The working fluid in gas phase is sent to the condensing unit 3 via the vapor tube 4.

[0026] Since the temperature of the working fluid lowers while the heat of the working fluid passing through the inside (pipe 31) is discharged to the outside via the fins 32, the working fluid condenses in the condensing unit 3 and changes from gas phase into liquid phase. The working fluid that has changed into liquid phase moves to the evaporating unit 2 through the liquid tube 5 through the liquid tube 5 and permeates the wick 6 disposed inside the heat receiving unit 7 again from the reservoir 8 due to capillary action. The heat of the heating unit is continuously discharged outside in such circulations of the working fluid, thereby cooling a subject to be cooled.

[0027] The drawbacks of a typical loop heat pipe including a wick inside an evaporator is described referring to the drawings here.

[0028] FIG. 3 is a schematic diagram illustrating a typical loop heat pipe 100.

[0029] In general, the loop heat pipe 100 includes an evaporating unit 102 for evaporating and changing working fluid from liquid phase to gas phase upon receipt of heat from outside and a condensing unit 103 for condensing the working fluid from gas phase to liquid phase by discharging heat to the outside as illustrated in FIG. 3. It also includes a vapor tube 104 for sending the working fluid in gas phase from the evaporating unit 102 to the condensing unit 103 and a liquid tube 105 for sending the working fluid in liquid phase from the condensing unit 103 to the evaporating unit 102.

[0030] A wick 106, made of a porous medium (material), is included inside the evaporating unit 102. The working fluid sent from the liquid tube 105 permeates fine holes of the wick 106 due to capillary action and oozes to the outer surface of the wick 106. The heating unit (subject to be cooled) in contact with the evaporating unit 102 transfers heat to the wick 106 via the housing of the evaporating unit 102. The working fluid changes into gas owing to this heat. The working fluid that has changed into gas phase moves to the condensing unit 103 via the vapor tube 104.

[0031] At the condensing unit 103, the heat of the working fluid is discharged outside. Owing to this heat discharging, the working fluid is cooled and changed into liquid. The working fluid that has changed into liquid moves to the evaporating unit 102 via the liquid tube 105 and permeates the inside of the wick 106 again. This loop heat pipe 100 circulates the working fluid utilizing the phase change thereof and transfers the heat absorbed at the evaporating unit 102 to the condensing unit 103, thereby efficiently cooling the subject to be cooled.

[0032] To enhance the cooling efficiency, attachability with the evaporating unit 102 should be secured to circulate the working fluid owing to capillary force of the wick 106 and the pressure loss should be minimized. To achieve this, the wick 106 is required to have a high level of permeability.

[0033] As the wick, porous sintered compact molded by filling with aluminum fiber and porous elastic body such as foamed silicone rubber can be used. In the case of a wick of a porous sintered compact, a high level of dimension accuracy is required to secure the attachability to a housing. This configuration is not cost effective. The wick 6 constituted of a porous elastic body is preferable. The wick 6 constituted of a porous elastic body is highly elastic so that it can be suitably attached to the housing (heat receiving unit 7) of the elastic body 2 irrespective of the dimension accuracy, which contributes to cost efficiency. The wick 6 constituted of a porous elastic body is suitably attachable. This configuration makes it possible to efficiently transfer heat from the housing of the evaporating unit 2 to the wick 6, thereby enhancing the cooling performance of the loop heat pipe 1.

[0034] The wick 6 can secure high attachability of the wick 6 and prevent voids from being locally crushed just when the wick 6 is made of a porous elastic body. The manufacturing cost can be further reduced by forming conveyance grooves such as the grooves 10 for conveying the working fluid (evaporation coolant) without post-processing.

[0035] When the loop heat pipe 1 is used for an application requiring a high cooling performance, it is preferable to use water having a high latent heat as working fluid. When water is used as the working fluid, a porous medium such as foamed silicone rubber is not sufficiently hydrophilic so that the working fluid minimally permeates the wick 6. The cooling performance may deteriorate in this combination.

[0036] In the present embodiment, hydroxyl group (-OH) as a hydrophilic group is added to the inside of a porous medium by hydrophilizing treatment such as plasma treatment to maximize the proportion of oxygen in the elemental composition ratio at the surface of voids of the porous medium. Due to the hydrophilic treatment to make the oxygen proportion preferably 40 percent or more, more preferably 50 percent or more, water as the working fluid can be efficiently circulated to achieve a high cooling performance. Hydrophilic fluid like water such as alcohol, e.g., ethanol having a hydrophilic substituent, can be also efficiently circulated as working fluid.

[0037] One example of the wick 6 in the present embodiment is described in detail below.

[0038] The wick 6 for use in the loop heat pipe 1 relating to the present embodiment is made of porous elastic body such as foamed silicone rubber as described above.

[0039] There are variety of methods for manufacturing a wick made of such porous elastic body. One way of obtaining the porous elastic body of the present embodiment is to use and apply a technology proposed as water-blown silicone rubber.

[0040] Specifically, using water-blown silicone rubber composition, stirring is conducted in such a manner that voids as spherical voids present in the cross section obtained by cutting an obtained foam are present satisfying the following: The voids formed in the cross section have a size of from 0.1 to 50 μm ; and the voids having a size of from 5 to 10 μm have the largest proportion of all of the voids.

[0041] Specifically, the porous elastic body mentioned above is obtained in the following manner. A procurable liquid silicone rubber of two liquid type with a catalyst, a surfactant, and a cross-linking agent. The obtained mixture is admixed with a liquid mixture obtained by mixing optionally alcohol added water with substances such as an additive, a filler, and a dispersant, which is prepared to have the same viscosity as the liquid silicone rubber, followed by stirring to obtain an emulsion composition. The liquid silicone rubber preferably has a specific gravity of from 1.00 to 1.05 (g/cm^3) considering emulsification with water.

[0042] The mixing ratio of the liquid silicone rubber and the liquid mixture depends on desired void ratio.

[0043] A foam with a void ratio of 50 percent can be obtained at a mixing ratio of the liquid silicone rubber and the liquid mixture one to one because the particulate moisture in the emulsion evaporates, which results in forming of voids.

[0044] The emulsion is prepared using a homogenizer or a stirring device capable of ultrasonic wave treatment under stirring conditions such as a stirrer, a stirring time, and a stirring speed (for example, from 300 to 1,500 rpm) adjusted to obtain a void diameter distribution satisfying the conditions mentioned above.

[0045] Thereafter, a die is filled with the thus-prepared emulsion composition followed by heating for the first time to cure silicone rubber without vaporizing moisture in the emulsion composition.

[0046] The heating temperature is from 80 to 130 degrees C and the heating time is from 30 to 120 minutes. The heating temperature is preferably from 90 to 110 degrees C and the heating time is preferably from 60 to 90 minutes. Next, the foam obtained after the heating for the first time is subjected to heating for the second time. The heating temperature is from 150 to 300 degrees C and the heating time is from 1 to 24 hours. The heating temperature is preferably from 200 to 250 degrees C and the heating time is preferably from 3 to 8 hours. Owing to such heating for the second time, the porous elastic body is purged of moisture to obtain foam having complex voids in which spherical voids partially overlap, which is a continuous void type. At the same time, the silicone rubber is finished with curing.

[0047] Next, to enhance dimension accuracy and remove skin layers on a necessity basis, the outer surface of the wick is shaved off several μm to several mm. For example, a whet stone or tape is used for the shaving. Powder produced during shaving and impurities are then removed by rinsing. Specifically, such powder and impurities are removed by ultrasonic rinsing or baking.

[0048] The wick is further subjected to hydrophilizing treatment to add hydrophilicity. Such treatment is conducted using corona, plasma, and UV ozone or hydrophilic coating is used. Alternatively, it is good to use a material containing an additive for applying hydrophilicity. Such hydrophobizing treatment is applied not only to the outer surface of silicone rubber but also to the passage including the surface of voids the inside on which the working fluid flows. The surface of voids means the portion in the wick which contacts the voids. It is preferable to hydrophilize the inside by a method using corona, plasma, or UV ozone first and then apply hydrophobic coating to obtain stable hydrophilicity over time.

[0049] The specifications and conditions during manufacturing of the cross section obtained by cutting water-blown silicone rubber as porous elastic body that has been completely cured are further described in detail.

Void Diameter Peak

[0050] The porous elastic body for use in the wick 6 drives the loop heat pipe 1 by moving working fluid due to its capillary force. The diameter of the void of the porous elastic body is preferably small to obtain a larger capillary force.

[0051] The relationship between the diameter r_{wick} (radius of void of wick) of a void of porous elastic body for use in the wick 6 and the capillary force (capillary pressure: ΔP_{cap}) are represented by the following relationship 1:

$$\Delta P_{\text{cap}} = 2\sigma \cos\theta / r_{\text{wick}} \quad \text{Relationship 1}$$

σ represents a surface tension of working fluid and θ represents a contact angle of wick and working fluid.

[0052] As seen in the relationship 1, the capillary pressure increases as the radius of a void of a wick decreases. To operate the loop heat pipe 1, capillary force (capillary pressure: ΔP_{cap}) and total pressure loss (ΔP_{total}) need to satisfy the following relationship 2.

$$\Delta P_{\text{cap}} \geq \Delta P_{\text{total}} \quad \text{Relationship 2}$$

[0053] Total pressure loss (ΔP_{total}) is obtained by the following relationship 3.

$$\Delta P_{\text{total}} = \Delta P_{\text{wick}} + \Delta P_{\text{groove}} + \Delta P_{\text{VL}} + \Delta P_{\text{cond}} + \Delta P_{\text{LL}} + \Delta P_{\text{grav}} \quad \text{Relationship 3}$$

ΔP_{wick} represents the pressure loss of wick, ΔP_{groove} represents the pressure loss of groove, ΔP_{VL} represents the pressure loss of vapor tube, ΔP_{cond} represents the pressure loss of condensing unit, and ΔP_{LL} represents the pressure loss of liquid tube, and ΔP_{grav} represents the pressure loss due to gravity.

[0054] As described above, the maximum diameter of a void of a porous elastic body is preferably small. For example, 50 μm or less is preferable. When the maximum diameter of a void is greater than 50 μm , the capillary force becomes insufficient to operate a loop heat pipe. It is preferably 30 μm or less and more preferably 10 μm or less.

[0055] The maximum diameter of a void of 1 μm or less or even 0.1 μm or less is sufficient to operate a loop heat type if a wick is extremely thin. However, the minimum diameter of a void is preferably 0.1 μm or greater. The maximum diameter of a void is obtained by: taking an image of the cross section of a porous elastic body with a laser microscope; image processing the image; and measuring the area of voids in the image processed image.

Void ratio

[0056] The larger the void ratio of the porous elastic body for use in the wick 6, the more advantageous to operate the loop heat pipe 1. The void ratio is preferably 20 percent or more. When the void ratio is less than 20 percent, operating the loop heat pipe 1 is difficult. More preferably, it is 50 percent or greater. The void ratio can be calculated according to the following relationship 4.

$$\text{Void ratio (percent)} = (\text{specific gravity of solid} - \text{specific gravity of porous elastic body}) / (\text{specific gravity of solid}) \times 100 \quad \text{Relationship 4}$$

Diameter of Continuous Void

[0057] Continuous voids in the wick 6 represent portions where voids (cells) communicate each other and the capillary force for driving working fluid works. The diameter of continuous voids is preferably 10 μm or less and more preferably 5 μm or less to enhance the cooling performance. It is preferable that the average void diameter of the continuous voids be 3 μm or less. In this range, it is possible to suitably strike a balance between the capillary force and permeability of the wick 6 at a high level.

[0058] The diameter of a continuous void of 1 μm or less or even 0.1 μm or less is sufficient when the wick 6 is extremely thin.

[0059] The continuous void diameter is measured according to the bubble point method and the obtained maximum void diameter is determined as the continuous void diameter.

[0060] A gas pressure is applied to a porous elastic body completely dipped in a test liquid. The pressure at which bubbles appear is determined as the bubble point. The continuous void diameter (maximum diameter) is calculated according to the following relationship 5 using a test liquid whose surface tension is already known.

$$d = 4\sigma\cos\theta/\Delta P \quad \text{Relationship 5}$$

[0061] In Relationship 5, d represents the continuous void diameter (maximum diameter), σ represents the surface tension of working fluid, θ represents the contact angle between wick and working fluid, and ΔP represents the pressure loss (bubble point pressure).

[0062] The average particle diameter of the continuous void diameter can be obtained by the bubble point method. The average void diameter of continuous voids is obtained by: obtaining the pressure ΔP at an intersection between the pressure-amount of flow curve for the state in which a porous elastic body is dipped and the pressure-amount curve (half dry curve) where the amount of flow is 1/2 of the amount of flow measured in dried state; and assigning the obtained pressure ΔP in the relationship 5 mentioned above.

Evaluation on Hydrophilicity

[0063] Hydrophilicity of the wick 6 is evaluated base on the elemental composition ratio at three points of the outer surface on the heat receiving side attached to the inner surface of the wall part having a surface in contact with the heating portion (subject to be cooled) of the heat receiving unit 7, the outer surface opposite to the outer surface on the

heat receiving side, and the center of the cross section. Three elements of silicon (Si), carbon (C), and oxygen (O) are subjected to quantity analysis for elemental analysis by X-ray photoelectron spectroscopy (XPS). The proportion of oxygen is used for the evaluation. In the present embodiment, the two main elements of silicone rubber, which are carbon and silicon, and oxygen applied by hydrophilization treatment are subjected to quantity analysis and hydrophilicity is evaluated based on the proportion oxygen. Four or more elements including the three elements can be subjected to quantity analysis followed by evaluation based on the proportion of oxygen. In either quantity analysis, the surface of voids can be suitably hydrophilic when the proportion of oxygen is the largest at the surface. This proportion enhances the permeability of water to a wick.

Test on Cooling Performance

[0064] Next, the cooling performance test in Examples which satisfy the ranges of the conditions of the wick 6 mentioned above and Comparative Examples outside the ranges are described with reference to the drawings.

1. Electronic Device (Projector) That Suitably Includes Wick for Use in Cooling Performance Test

[0065] FIG. 4 is a schematic diagram illustrating another example of the loop heat pipe 1 equipped in the electronic device 20 relating to an embodiment of the present disclosure. It also illustrates a cooling device 40 including the loop heat pipe 1.

[0066] Unlike the example illustrated in FIG. 1, the example of the loop heat pipe 1 illustrated in FIG. 4 includes a wick having a size a little larger than the inner diameter of the cylindrical inner space of the housing of the evaporating unit 2. The wick is pressed in the housing of the evaporating unit 2.

[0067] The loop heat pipe 1 illustrated in FIG. 1 can be used in place of the loop heat pipe illustrated in FIG. 4 as the cooling device for the electronic device relating to the present embodiment; however, the device illustrated in FIG. 4 was used in the cooling performance test in each Example and Comparative Example which are described later.

[0068] The electronic device 20 illustrated in FIG. 4 is a projector equipped with an optical unit 21, which is an example to which the present embodiment is applied.

[0069] The electronic device to which the loop heat pipe 1 relating to the present embodiment is not limited to a projector. It can be applied to, but is not limited to, an image forming apparatus such as a printer, a photocopier, a facsimile machine, and a multifunction peripheral thereof, and an electronic device such as a home computer, a server, an electronic blackboard, a TV set, a blu-ray recorder, and video game console.

[0070] The loop heat pipe 1 and the cooling device relating to the present embodiment can be applicable to items other than such electronic devices. Such items include cooling devices for cooling a chemical plant equipped with a reaction furnace. The loop heat pipe 1 and the cooling device relating to the present embodiment can be applicable to a vessel or a building accompanied with an electronic device such as server rack.

[0071] The evaporating unit 2 (the heat receiving unit 7 in particular) of the loop heat pipe 1 illustrated in FIG. 4 is disposed in contact with the heating unit of the optical unit 21. The evaporating unit 2 cools the subject to be cooled (heating unit, optical unit, or projector) by absorbing heat from the heating unit.

[0072] The condensing unit 3 is disposed close to an exhaust fan 22 disposed on the side of the housing of the projector. An air current happens around the condensing unit 3 by the exhaust fan 22 exhausting air to the outside. The air current cools the condensing unit 3, thereby enhancing the effect of heat radiation at the condensing unit 3.

[0073] An air inlet 23 is disposed on the side of the housing opposite to the side of the housing on which the exhaust fan 22 is disposed. Air suctioned from the air inlet 23 is exhausted from the exhaust fan 22 via the projector. FIG. 4 also illustrates a cooling device 40 for cooling a projector. The cooling device 40 includes the loop heat pipe 1 and the exhaust fan 22 for enhancing the effect of heat radiation of the loop heat pipe 1. The exhaust fan 22 can be replaced with a blowing fan for supplying air to the condensing unit 3. A cooling device equipped with the loop heat pipe 1 without a fan is also allowable.

2. Detailed Examples and Comparative Examples

[0074] FIG. 5 is a table showing the specifications of samples for use in the cooling performance test in Examples and Comparative Examples and the test results thereof.

[0075] In the test, the samples of the wick 6 in Examples were prepared using a water-blown silicone rubber as shown in FIG. 5. The samples of water-blown silicone rubber of the wick 6 of Comparative Examples were manufactured for continuous (complex) foam and independent foam. The sample of porous aluminum of the wick 6 in Example 4 illustrated in FIG. 4 was manufactured by sintering aluminum powder. Each sample manufactured was used as the loop heat pipe 1 carried in a projector as illustrated in FIG. 4. It was subjected to the cooling performance test.

[0076] The state of the foam was determined as complex when the voids observed with a laser microscope were

confirmed to be adjacent to each other and form a complex foam. The state of the foam was determined as independent when not confirmed to be complex. FIG. 6 is a photo of the state of the void of the sample of the wick 6 of Example 1 taken by a laser microscope. As seen in the photo, the voids are adjacent to each other and form a complex state. The void state of Example 1 is determined as complex. Examples 1, 2, 3 and Comparative Examples 1, 2, and 3 were

subjected to this evaluation.

[0077] The diameter range of voids and the mode of the void diameter were obtained from the void diameter distribution, which was obtained by taking an image with a laser microscope and image processing the image followed by calculation.

[0078] FIG. 7 is a graph illustrating an example of the void diameter distribution. The bold line represents the distribution of the water-blown silicone rubber of Examples 1, 2, and 3, which are complex voids. The fine line represents the distribution of the water-blown silicone rubber of Comparative Example 1, which are independent void. The distribution of the void diameter (μm) is represented by the probability density function. The X axis represents the void diameter (μm) and the Y axis represents the probability density. The image processing is calculated by sieving the number (frequency) in a certain void diameter range (μm). It is the number (probability) of voids present in a certain void diameter range (μm) in all the voids in the image processing range. The mode of the void diameter is obtained from this void diameter distribution.

[0079] The void diameter distribution illustrated in FIG. 7 shows the void diameter distribution to a void diameter of 32 μm or less. It is also suitable to calculate the number of voids having a diameter of 32 μm or greater. The minimum value of the void diameter range was obtained based on the calculated void diameter distribution. The maximum value was obtained by the area of voids according to the image processing of the image taken by a laser microscope as described above.

[0080] As seen in FIG. 7, the mode of the diameter of voids of Example 1, which were complex voids, was 5 μm , including many voids of 10 μm or less. However, the mode of the void diameter of the water-blown (independent void) silicone rubber of Comparative Example 1 was 20 μm and many voids of 15 μm or more were present therein.

[0081] The void ratio was calculated according to the relationship 4. The diameter of continuous void was obtained by measuring the bubble point pressure using the bubble point method as described above and calculating according to the relationship 5. A gas permeation fine void diameter distribution measuring device (PROMETER 3G, manufactured by Anton Paar Japan K.K.) that can execute the bubble point method according to JIS K3832 was used to measure the diameter of continuous voids. The measuring sample had $\Phi 25$ and POLOFIL was used as wetting fluid. The average void diameter of the continuous void is obtained by: obtaining the pressure ΔP at an intersection between the pressure-amount of flow curve measured by the bubble point method as described above and the pressure-amount curve (half dry curve) where the amount of flow is 1/2 of the amount of flow measured in dried state; and assigning the obtained pressure ΔP in the relationship 5 mentioned above.

[0082] FIG. 8 is a photo of a sample of the wick of Example 1 when the sample is observed with a scanning electronic microscope. FIG. 8 is an enlarged image of the image illustrated in FIG. 6, which is observed with a laser microscope. The black voids in FIG. 8 are continuous voids. The size of these continuous voids can be confirmed to be 5 μm or less.

[0083] For outer surface hydrophilicity and inside hydrophilicity, the proportion analysis of silicon (Si), carbon (C), and oxygen (O) were conducted at the two sites of the outer surface of a wick and the inside, which was the cross section obtained by dividing the wick in two along the thickness direction. This is to check if hydrophilicity is applied to the surface of voids inside of the wick. If so, the working fluid is efficiently conveyed. K-Alpha™ of Thermo Fisher Scientific K.K. was used for XPS analysis with an analysis area of about $\Phi 400 \mu\text{m}$. The sample was cut into suitable sizes. The outer surface on the heat receiving side, the outer surface on the opposite side to the outer surface on the heat receiving side, and the surface of the void inside were subjected to analysis. The outer surface hydrophilicity is the average of the proportion of Si:C:O at the total of six sites of three sites of the outer surface on the heat receiving side and three sites of the outer surface on the opposite side to the outer surface on the heat receiving side. The inside hydrophilicity is the average of the proportion of Si:C:O at the three sites of the inside.

[0084] FIG. 9 is a graph showing the proportion of silicon to carbon to oxygen when the elements at the surface of a representative sample of the wick 6 for use in Example 1 are analyzed by X-ray photoelectron spectroscopy (XPS). It shows that the proportion of oxygen is the highest.

[0085] Cooling performance, attachability of wick, and heat resistance of wick were evaluated in the cooling performance test.

[0086] The cooling performance was evaluated by applying an electricity of 100 W to a projector and measuring the temperature of the evaporator after the state was held for 10 minutes. The temperatures at the evaporator were ranked in order of increasing.

[0087] The samples were comprehensively rated for the test results as A, B, or C in view of cooling performance, attachability, heat resistance, and cost.

[0088] The heat receiving unit 7 equipped with the wick 6 was observed with X-ray computed tomography (CT) scan to evaluate the attachability of the wick 6 and rated as follows:

A: No gap between the heat receiving unit 7 and the wick 6

C: Gap present between the heat receiving unit 7 and the wick 6

[0089] Heat resistance of the wick 6 was evaluated as follows: the heat receiving unit 7 was heated by applying 200 W to the heater followed by a durability test for 100 hours; and the wick 6 was removed from the heat receiving unit 7 and visually checked; the wick 6 was evaluated according to the following:

A: no plastic deformation causing damage to or gap in the wick 6

C: plastic deformation causing damage to or gap in the wick 6

Examples 1, 2, and 3

[0090] In Examples 1, 2, and 3, active agents and polymers were selected to prepare water-blown silicone rubber in such a manner that complex voids were formed. Hydrophilizing treatment was plasma treatment alone in Examples 1 and 2 whereas it was plasma treatment with impregnation of coating agent of silicon dioxide in Example 3. In Examples 1 and 2, the void diameter modes were adjusted to be respectively 5 μm and 10 μm by changing the stirring conditions during the preparation of emulsion.

[0091] In Examples 1, 2, and 3, excellent cooling performance was achieved in the cooling performance test. The cooling performance was the best in Example 3, in which the plasma treatment was conducted with the impregnation of silicon dioxide. The cooling performance were on the same level in Examples 1 and 2.

[0092] The following considerably explains why such good cooling performance was achieved. First, the water-blown silicone rubber of Examples 1, 2, and 3 are subjected to dehydration reaction of aqueous phase and cross-linking of rubber at the same time during secondary heating. Continuous voids between voids are efficiently formed and the void ratio is high because the voids are complex voids. Therefore, the working fluid suitably permeates the wick 6. In Examples 1, 2, and 3, since the void diameter mode was 10 μm or less and the average void diameter of the continuous void was 3 μm or less, many fine continuous voids were considered to be formed. Thus, the obtained wick is thought to have a high capillary force.

[0093] The working fluid can be thus suitably circulated in such a wick and the cooling efficiency is enhanced. As a result, the cooling performance is enhanced.

[0094] Moreover, owing to the usage of water having a high latent heat as the working fluid, the wick can deprive a subject of a large quantity of heat while the working fluid is changed from liquid into gas, which enhances the cooling performance. Furthermore, in Examples 1, 2, and 3, the wick 6 is hydrophilized to the surface of the continuous void as the passage of the working fluid to increase the proportion of oxygen at the surface of the continuous void. The working fluid of water readily permeates the wick by increasing the proportion of oxygen at the surface of the continuous void to the highest. Consequently, the working fluid can be suitably circulated and the cooling efficiency is enhanced so that the cooling performance is enhanced.

[0095] While the proportion of oxygen inside in Examples 1 and 2 subjected to plasma treatment alone was about 50 percent, it was about 60 percent at the inside in Example 3, which was hydrophilized by plasma treatment and silicon dioxide coating in combination. The difference between the inside and the outer surface of the wick regarding the proportion of oxygen was reduced in Example 3, which indicates that even the surface of voids inside the wick was steadily hydrophilized. That is, owing to this combination of the plasma treatment and treatment film of silicon dioxide coating, the surface of the void inside can be steadily hydrophilized. The permeability of the working fluid can be further enhanced by such a combination, thereby further enhancing the cooling efficiency. As a result, in comparison with Examples 1 and 2, the temperature of the evaporating unit 2 was low. This explains why Example 3 was the best regarding the cooling performance. Like Example 3, stabilization over time can be expected due to the combinational use with a treatment film of silicon dioxide coating.

[0096] The evaluation regarding attachability was A in Examples 1, 2, and 3. This is partly because the silicon rubber, which was a porous elastic body, was used as a wick, and partly because the wick 6 was manufactured a little larger the inside dimension of the housing of the heat receiving unit 7 of the evaporating unit 2, which gave a high attachability between the wick 6 and the housing. Such a high attachability enhances the heat transfer efficiency to the wick 6, thereby improving the cooling efficiency. This is also considered to be a factor of enhancing the cooling performance in Examples 1, 2, and 3.

[0097] In Examples 1, 2, and 3, since the wick 6 was constituted of silicone rubber, deformation causing damage to or gap in the wick 6 did not happen after the heat resistance test. These were rated A.

[0098] The test results of Examples 1, 2, and 3 were also rated A in view of the cooling performance and the cost.

Example 4

[0099] In Example 4, porous aluminum sample, prepared by sintering aluminum powder that includes voids and continuous voids formed among particles was used as the wick. A wick having the same void ratio and void diameter range of from 0.1 to 50 μm as in Example 1 was obtained by controlling the sintering condition and particle diameter. The void diameter mode was a little large, which was 10 μm . In Example 4, the void means that void in the porous aluminum, and the void diameter means diameter of the void as measured by the same procedure as in Example 1. The voids are connector with the continuous void so that the wick of Example 4 includes complex voids shown in FIG. 5.

[0100] In Example 4, a gap was present between the housing (heat receiving unit 7) and the wick 6. Example 4 was rated C regarding attachability. Both the housing and the wick 6 being hard material was considered to cause this gap. Extremely high precision is required to attach hard materials such as the housing and the wick, to each other without creating a gap therebetween. Moreover, processing without crushing voids is technically difficult, which increases the cost for mass production.

[0101] Example 4 was not evaluated as good as Examples 1, 2, and 3 regarding the cooling performance.

[0102] Poor attachability of the wick with the housing degraded the cooling efficiency in Example 4, which explains why the cooling performance was worse than Examples 1, 2, and 3. However, in Examples 4, the void diameter mode was 10 μm or less, the average diameter of continuous void was 3 μm , and the proportion of oxygen at the surface of the continuous void was the highest. Regarding the cooling performance, Example 4 was better than Comparative Examples 1 to 3 and satisfied the purpose of practical use. Although the cooling performance is good in Example 4, the cost increases in terms of attachability. The test result of Example 4 was rated B.

Comparative Example 1

[0103] In Comparative Example 1, water-blown silicone rubber was used to make the wick have independent voids. The size of the void was in a range of from 0.1 to 50 μm . The mode of the void diameter was 20 μm , which was large in comparison with Examples 1, 2, and 3. The void ratio was 60 percent at best. Since the void ratio was lower than Examples 1, 2, and 3, the permeability of the working fluid to the wick is considered to be poor in comparison with Examples 1, 2, and 3. Considering the void diameter being about twice as large as in Examples, the capillary force is considered to be weak.

[0104] In Comparative Example 1, plasma treatment was conducted under the same condition as Examples 1 and 2. However, as seen in the inside hydrophilicity shown in FIG. 5, the proportion of silicon was the highest at the inside. That is, the inside was not sufficiently hydrophilized because the inside could not be hydrophilized to a degree that the proportion of oxygen became the highest. In the case of an independent void, the distance between voids is long and the void ratio is low. Therefore, the hydrophilizing treatment was considered to be not sufficient at the inside in comparison with Examples 1 and 2, which were complex voids and had a high void ratio. This insufficient hydrophilizing treatment leads to poor hydrophilicity between the surface of a void and water as the working fluid. Thus, the working fluid did not permeate the wick 6 well in comparison with Examples 1 and 2.

[0105] Due to this permeability, the working fluid did not permeate the wick well in Comparative Example 1 so that the circulation efficiency of the working fluid was inferior to that in Examples, which leads to excessively poor cooling performance. Therefore, the test result of Comparative Example 1 was evaluated C.

[0106] However, since the wick 6 was constituted of silicone rubber of porous elastic body in Comparative Example 1, the wick 6 was manufactured a little larger than the inside dimension of the housing of the heat receiving unit 7 of the evaporating unit 2 taking advantage of the elasticity of silicone rubber. The attachability was rated A and the heat resistance was also rated A.

Comparative Example 2

[0107] The wick of Comparative Example 2 was the same as that of Example 2 except that the wick of Comparative Example 2 was not subjected to hydrophilizing treatment.

[0108] Ethanol was used as the working fluid in Comparative Example 2. Since ethanol has a smaller latent heat than water, the working fluid is deprived of a less amount of heat when changing from liquid phase to gas phase. Therefore, the cooling efficiency was low in comparison with Examples so that the cooling performance was significantly poor. The test results was rated C for Comparative Example 2. Since ethanol was used as the working fluid in Comparative Example 2, no hydrophilizing treatment was thought to have little impact.

Comparative Example 3

[0109] Like Comparative Example 2, the wick of Comparative Example 3 was the same as that of Example 2 except

that the wick of Comparative Example 3 was not subjected to hydrophilizing treatment. Water was used as the working fluid in Comparative Example 3. Without hydrophilizing treatment, the surface of voids in silicone rubber is hydrophobic. Therefore, capillary force does not work so that water does not pass through the inside. It means that the working fluid does not move in the cooling performance test. Naturally, Comparative Example 3 is worst regarding the cooling performance. The test result was rated C.

[0110] As seen in the test results of the cooling performance test using the samples of Examples 1 to 4 and Comparative Examples 1 to 3 as described above, the following effect is confirmed in accordance with the specifications of the voids and continuous voids present at the cross section obtained by cutting the porous medium constituting the wick 6 of the present embodiment and the proportion of oxygen inside.

First and Second Specifications (Specifications of Examples 1 to 4)

[0111] In Examples 1 to 4, the proportion of oxygen is the highest in the elemental composition of the surface of voids and continuous voids (first specification). The size of the voids present on the surface is from 0.1 to 50 μm . The wick contains complex voids. The majority of the complex voids has a size of from 5 to 10 μm with continuous voids having a size of 5 μm or less present between voids (second specification).

Effect of Examples 1 to 4

[0112] The first specification enhances permeability of water as working fluid to the wick and makes it possible to further enhance the cooling performance of the loop heat pipe 1. The second specification enhances the capillary force and permeability to the wick. Therefore, good cooling performance is achieved in the cooling performance evaluation described above.

[0113] Comparative Example 1 is outside the second specification in that it is independent void and outside the first specification in that the proportion of oxygen of voids and at the surface of continuous voids is not the highest. Comparative Examples 2 and 3 are outside the first specification in that the proportion of oxygen is not the highest. Unlike Examples 1 and 2, ethanol is used as the working fluid in Comparative Example 2. Since water is used as working fluid in Comparative Example 3, the proportion of oxygen is low, which had an adverse impact on the test result. Regarding the cooling performance, Comparative Example 1 takes the fifth place, Comparative Example 2 takes the sixth place, and the comparative Example 3 takes the last place.

[0114] As seen in the comparison, the combination of the proportion of oxygen representing hydrophilicity and water is confirmed to have an impact on the cooling performance. Considering the results of Examples 1 and 2 and Comparative Example 1, it is found that the hydrophilizing treatment was effectively applied in the case of complex voids.

[0115] Example 4 satisfies the first specification (the proportion of oxygen is the highest at the surface composition of voids and continuous voids) and the second specification (the size of the voids present in the cross section is from 0.1 to 50 μm ; the wick contains complex voids; the majority of the complex voids has a size of from 5 to 10 μm with continuous voids having a size of 5 μm or less present between voids) except that the wick is not porous elastic body. Therefore, Example 4 demonstrates better cooling performance than Comparative Examples 2 and 3, which fail to satisfy the first specification, and comparative Example 1, which fails to satisfy the first and second specifications. Judging from this, it is obvious that good cooling performance is obtained when the first and second specifications are satisfied in comparison with the case where these specifications are not satisfied.

[0116] Third Specification (Specification of Examples 1 to 3 and Comparative Examples 1 to 3)

[0117] The third specification is that the porous medium is foamed silicone rubber as porous elastic body, more specifically, all of Examples 1 to 3 and Comparative Examples 1 to 3 is constituted of water-blown silicon rubber.

Effect of Examples 1 to 3 and Comparative Examples 1 to 3

[0118] As the wick 6 is a porous elastic body such as foamed silicone rubber, attachability between the wick 6 and the heat receiving unit 7 can be secured. Since the wick is foamed silicone rubber, the wick is heat-resistant.

[0119] The wick of Example 4 is made of metal (aluminum) and demonstrates heat resistance. However, it should be subjected to a high level of processing to enhance attachability because it lacks elasticity.

[0120] Having described the present embodiment with reference to the drawings, the specific configuration is not limited to that of the loop heat pipe 1 equipped with the wick 6 of the present embodiment described above. The designing can be modified within the scope of the present disclosure.

[0121] For example, each of the loop heat pipe 1 described with reference to FIGS. 1, 2, and 4 has a single evaporating unit 2 and a single condensing unit 3 as described above. However, the configuration of the loop heat pipe of the present embodiment is not limited thereto. The present embodiment can be applicable to a loop heat pipe having two or more evaporators 2 and/or two or more condensing units 3.

[0122] Each of the loop heat pipes 1 described with reference to FIGS. 1, 2, and 4 has a single wick 6 inside the evaporating unit 2 as described above. The loop heat pipe may be configured to have multiple wicks.

[0123] The above-described is just an example and the following aspects of the present disclosure have their own effects.

Aspect 1

[0124] A wick disposed inside an evaporator for changing working fluid from liquid phase to gas phase includes a porous medium a working fluid in liquid phase permeates, wherein oxygen has the largest proportion among carbon, silicon, and oxygen in the elemental composition at the surface of a void of the porous medium. The surface of a void means the portion in the wick which contacts a void.

[0125] As described in the cooling performance test, in the elemental composition at the surface of a void of the porous medium, good hydrophilicity is demonstrated when the oxygen proportion is the highest so that hydrophilic working fluid such as water permeates the wick well. Such good permeability enhances circularity of the working fluid. The cooling efficiency of the evaporator is enhanced when water is used.

Aspect 2

[0126] In Aspect 1, the oxygen proportion is the highest in the elemental composition of at the surface of a void of the porous medium.

[0127] According to this proportion, hydrophilic working fluid such as water permeates the wick well as described in Examples.

Aspect 3

[0128] In Aspect 1 or 2, the porous medium has complex voids having continuous voids at portions where multiple spherical voids such as voids partially overlap.

[0129] According to this proportion, hydrophilic working fluid such as water permeates the wick well as described in Examples. Hydrophilizing treatment is effectively conducted.

Aspect 4

[0130] In Aspect 3, the maximum void diameter of continuous void is 5 μm or less.

[0131] According to this, the capillary force of the wick can be increased as described in Examples.

Aspect 5

[0132] In Aspect 3 or 4, the average void diameter of continuous voids is 3 μm or less.

[0133] According to this, the capillary force of the wick can be increased as described in Examples.

Aspect 6

[0134] In any one of Aspects 3 to 5, the multiple spherical voids such as voids have a diameter of from 0.1 to 50 μm .

[0135] Owing to this, a suitable capillary force can be obtained as described in Examples.

Aspect 7

[0136] In any one of Aspects 3 to 6, the multiple spherical voids such as voids have a mode of from 5 to 10 μm in the distribution of diameters thereof.

[0137] Owing to this, a suitable capillary force can be obtained as described in Examples.

Aspect 8

[0138] In any one of Aspects 1 to 7, the porous medium is foamed silicone.

[0139] According to this, as described in Examples, the wick can be suitably attached and has good heat resistance.

Aspect 9

[0140] An evaporator such as the evaporating unit 2 for changing a working fluid in liquid phase to gas phase, which uses the wick of any one of Aspect 1 to 8.

5 **[0141]** This achieves good cooling performance.

Aspect 10

10 **[0142]** A loop-type heat pipe including an evaporator such as the evaporating unit 2 for changing a working fluid in liquid phase to gas phase upon a receipt of heat from outside and a condenser such as the condensing unit 3 that condenses the working fluid in air phase exhausted from the evaporator into liquid phase, which uses the evaporator of Aspect 9.

[0143] This achieves a good cooling performance.

15 Aspect 11

[0144] In Aspect 10, the working fluid is water.

[0145] According to this, good cooling performance is achieved by using water having a high latent heat.

20 Aspect 12

[0146] A cooling device equipped with the loop heat pipe of Aspect 10 or 11.

[0147] According to this cooling device, a subject to be cooled can be suitably cooled.

25 Aspect 13

[0148] The electronic device 20 such as a projector equipped with the cooling device of Aspect 12.

[0149] This cooling device can suitably cool the heating unit of the electronic device 20 such as a projector.

30 Aspect 14

35 **[0150]** A method of manufacturing a wick that is disposed in an evaporator such as the evaporating unit 2 for changing a working fluid in liquid phase to gas phase and includes a porous medium the working fluid in the liquid phase permeates, the method including subjecting the porous medium to treatment for making oxygen have the largest proportion among carbon, silicon, and oxygen of the elemental composition at the surface of a void of the porous medium.

[0151] According to this method, a wick can be manufactured which enhances the hydrophilicity of the surface of a void and which the working fluid of water suitably permeates.

[0152] Aspect 15 In Aspect 14, the method further includes forming complex voids having continuous voids at portions where multiple spherical voids such as voids partially overlap.

40 **[0153]** According to this method, a wick having a high capillary force can be manufactured.

Claims

45 1. A wick (6) disposed in an evaporator for changing a working fluid from liquid phase to gas phase, the wick (6) comprising:

a porous medium the working fluid in liquid phase permeates,
wherein oxygen has a largest proportion among carbon, silicon, and oxygen in an elemental composition at a
50 surface of a void of the porous medium.

2. The wick (6) according to claim 1, wherein oxygen has a largest proportion in the elemental composition at the surface of the void in the porous medium.

55 3. The wick (6) according to claim 1 or 2, wherein the porous medium comprises a complex void having a continuous void at a portion where multiple spherical voids partially overlap each other.

4. The wick (6) according to claim 3, wherein the continuous void has a maximum void diameter of 5 μm or less.

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9. An evaporator (2) for changing a working fluid from liquid phase to gas phase, comprising:
- the wick (6) of any one of claim 1 to 8.
- 15
10. A loop heat pipe (1) comprising:
- the evaporator (2) of claim 9; and
- a condenser (3) configured to condense the working fluid in gas phase exhausted from the evaporator (2) into liquid phase.
- 20
11. The loop heat pipe (1) according to claim 10, wherein the working fluid comprises water.
12. A cooling device (40) comprising:
- 25
- the loop heat pipe (1) of claim 10 or 11.
13. An electronic device (20) comprising:
- 30
- the cooling device (40) of claim 12.
14. A method of manufacturing a wick (6) disposed in an evaporator (2) for changing a working fluid from liquid phase to gas phase and includes a porous medium the working fluid in the liquid phase permeates, the method comprising:
- 35
- subjecting the porous medium to treatment of making oxygen have a largest proportion among carbon, silicon, and oxygen of an elemental composition at a surface of a void of the porous medium.
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15. The method according to claim 14, further comprising forming a complex void having a continuous void at a portion where multiple spherical voids partially overlap each other in the porous medium.
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FIG. 1

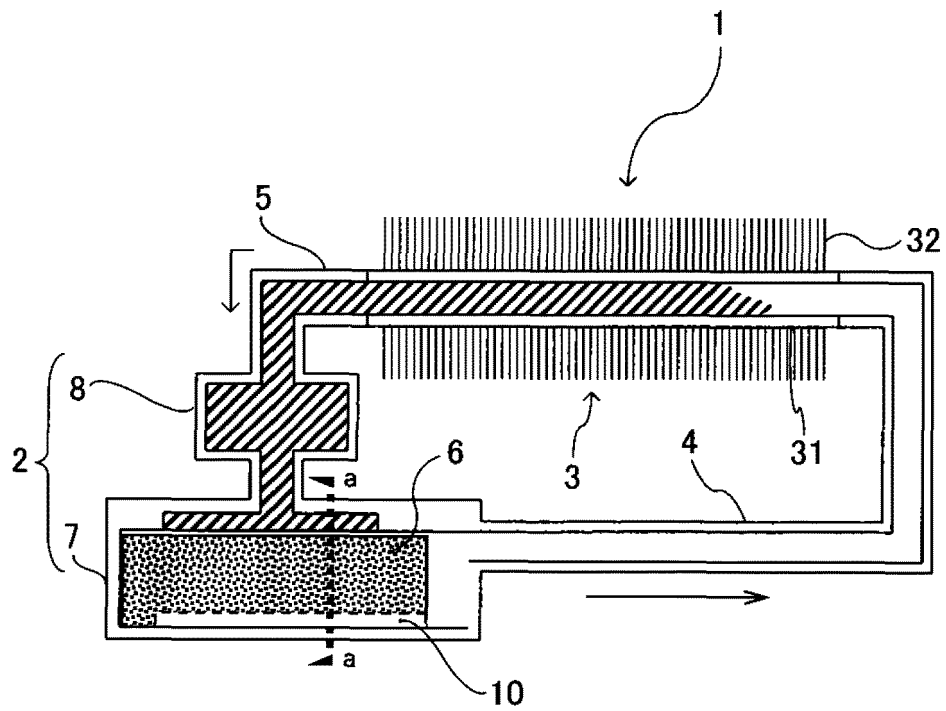


FIG. 2

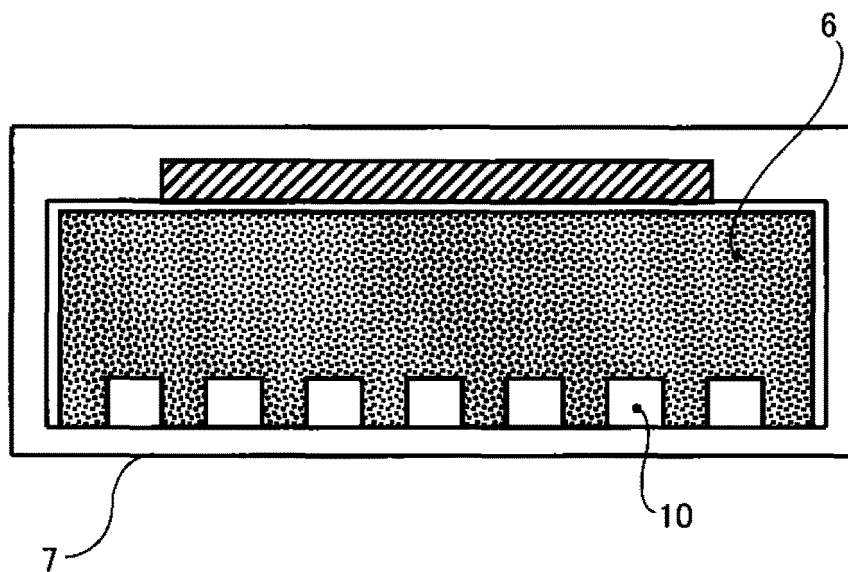


FIG. 3
BACKGROUND ART

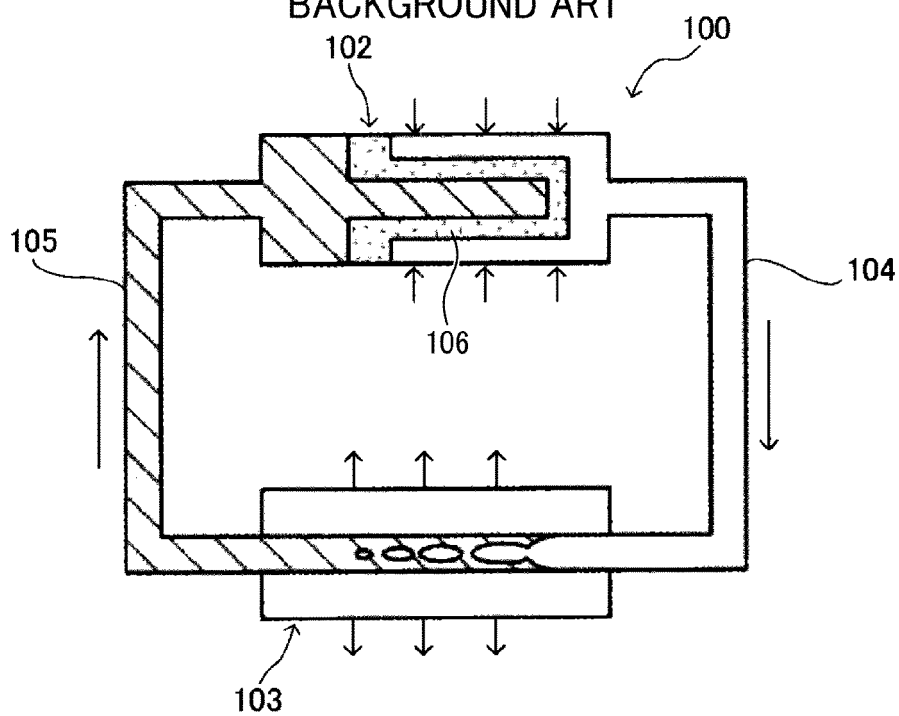


FIG. 4

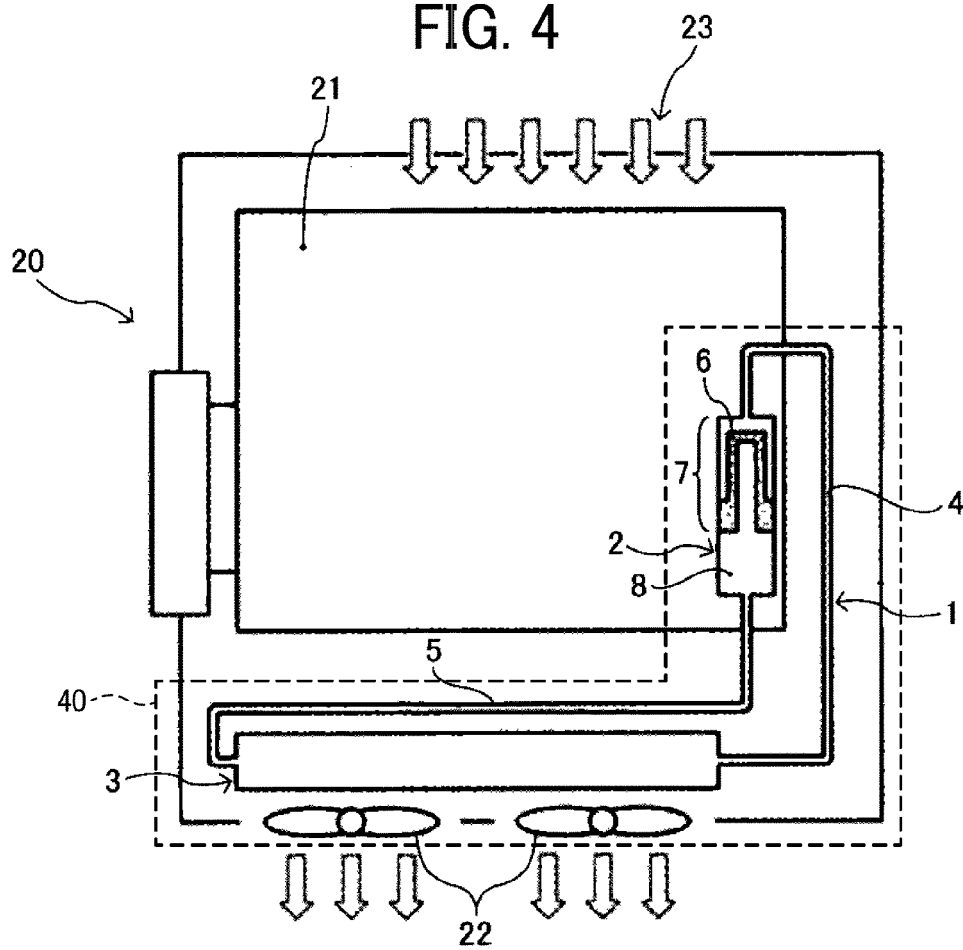


FIG. 5

		EXAMPLE 1	EXAMPLE 2	EXAMPLE 3	EXAMPLE 4	COMPARATIVE EXAMPLE 1	COMPARATIVE EXAMPLE 2	COMPARATIVE EXAMPLE 3
WICK	MATERIAL	SILICONE RUBBER	SILICONE RUBBER	SILICONE RUBBER	ALUMINUM	SILICONE RUBBER	SILICONE RUBBER	SILICONE RUBBER
	FORM OF VOID	COMPLEX	COMPLEX	COMPLEX	COMPLEX	INDEPENDENT	COMPLEX	COMPLEX
	HYDROPHILIZING TREATMENT	PLASMA	PLASMA	PLASMA + SiO ₂	PLASMA	PLASMA	NONE	NONE
	RANGE OF VOID DIAMETER (μm)	0.1-50	0.1-50	0.1-50	0.1-50	0.1-50	0.1-50	0.1-50
	MODE OF VOID DIAMETER (μm)	5	10	8	10	20	10	10
	VOID RATIO (μm)	70	70	65	70	60	70	65
	CONTINUOUS VOID AVERAGE DIAMETER (μm)	3	3	2	2	3	3	3
	CONTINUOUS VOID MAXIMUM DIAMETER (μm)	5	5	5	5	5	5	5
	SURFACE HYDROPHILICITY (c.o.s.i)	4:60:36	4:60:36	8:65:27	10:90:0	5:60:35	46:26:28	46:26:28
	INSIDE HYDROPHILICITY (c.o.s.i)	17:49:34	15:53:32	12:60:28	10:90:0	21:30:49	48:26:26	48:26:26
	WORKING FLUID	WATER	WATER	WATER	WATER	WATER	ETHANOL	WATER
	COOLING PERFORMANCE RANKING	2	2	1	4	5	6	7
PERFORMANCE	ATTACHABILITY	A	A	A	C HIGH PRECISION REQUIRED	A	A	A
	HEAT RESISTANCE	A	A	A	A	A	A	A
	TEST RESULT	A	A	A	B	C	C	C

FIG. 6

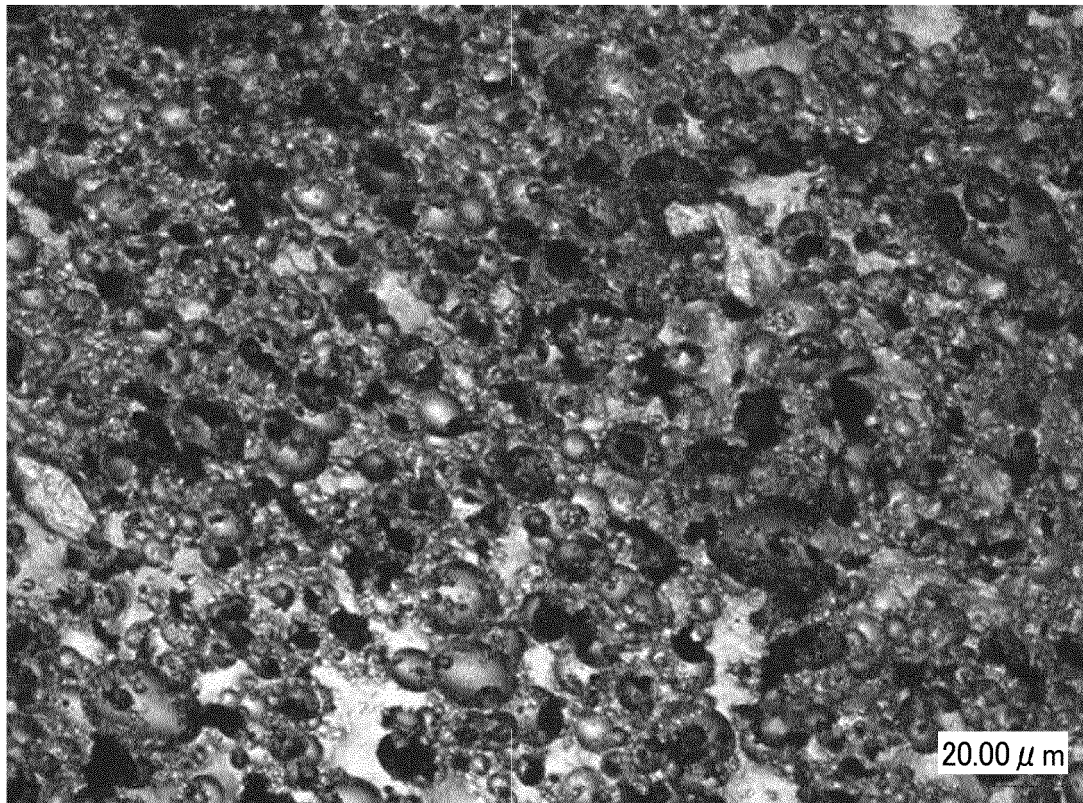


FIG. 7

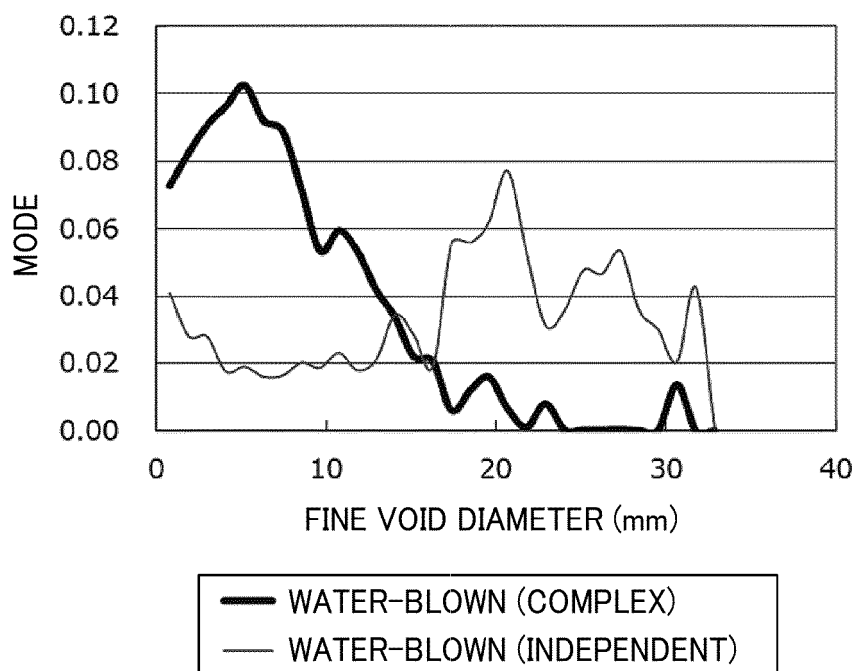


FIG. 8

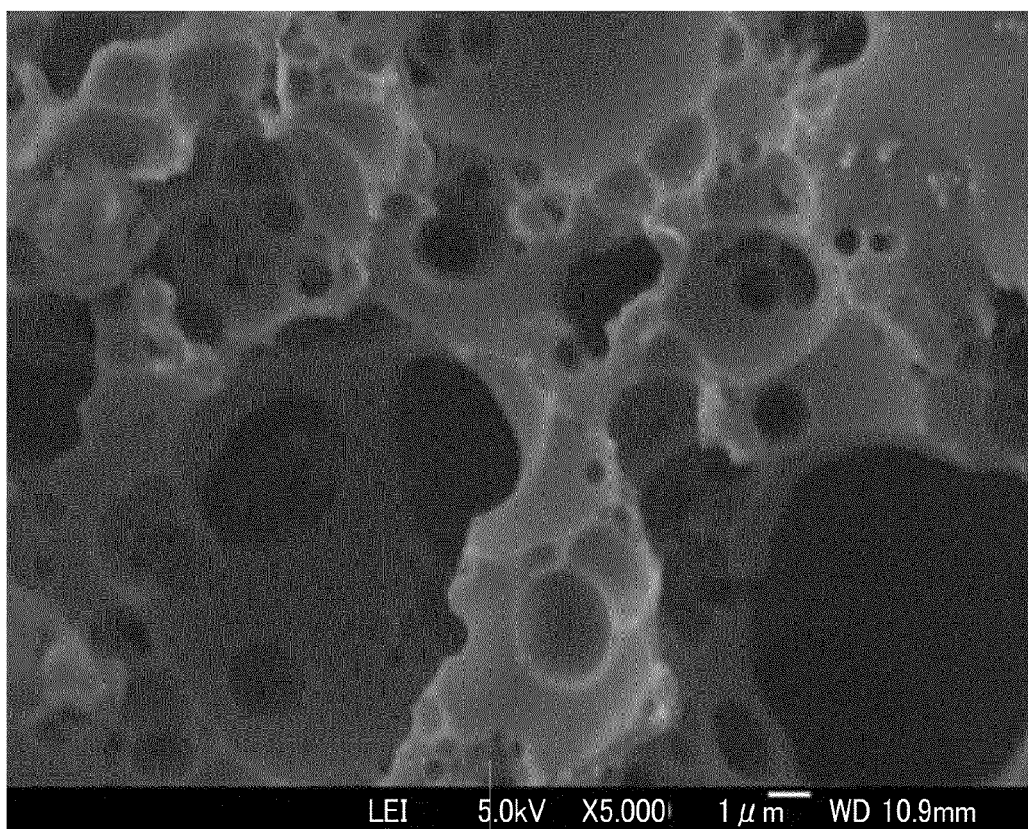
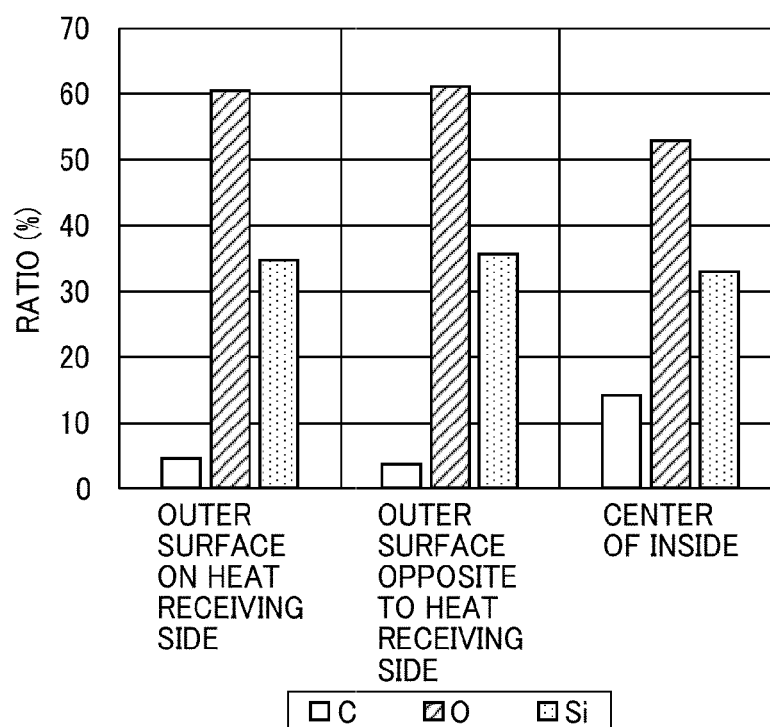


FIG. 9





EUROPEAN SEARCH REPORT

 Application Number
 EP 21 18 6585

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			F28F
The present search report has been drawn up for all claims			
Place of search Munich		Date of completion of the search 15 November 2021	Examiner Vassoille, Bruno
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document			

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 EPO FORM 1503 03.82 (P04C01)

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

EP 21 18 6585

5 This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
The members are as contained in the European Patent Office EDP file on
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15-11-2021

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