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Okuyama et al.(10) **Pub. No.: US 2010/0319884 A1**(43) **Pub. Date: Dec. 23, 2010**(54) **SELF-EXCITED OSCILLATING FLOW HEAT PIPE**(75) Inventors: **Kunito Okuyama**, Yokohama-shi (JP); **Shouji Mori**, Kamakura-shi (JP)Correspondence Address:
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Yokohama-shi (JP)(21) Appl. No.: **12/866,550**(22) PCT Filed: **Feb. 3, 2009**(86) PCT No.: **PCT/JP2009/051773**§ 371 (c)(1),
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F28D 15/04 (2006.01)(52) **U.S. Cl.** **165/104.26**(57) **ABSTRACT**

A self-excited oscillating flow heat pipe includes a heating unit having a wick therein; a cooling unit filled with a working fluid; a connection channel which rectilinearly connects the heating unit with the cooling unit, and has a smaller channel cross-sectional area than the channel cross-sectional area of the heating unit; a liquid plug protruding into the connection channel from the cooling unit and containing the working fluid; and a vapor plug in the heating unit containing the vaporized working fluid. The liquid plug oscillates self-excitedly in the connection channel.

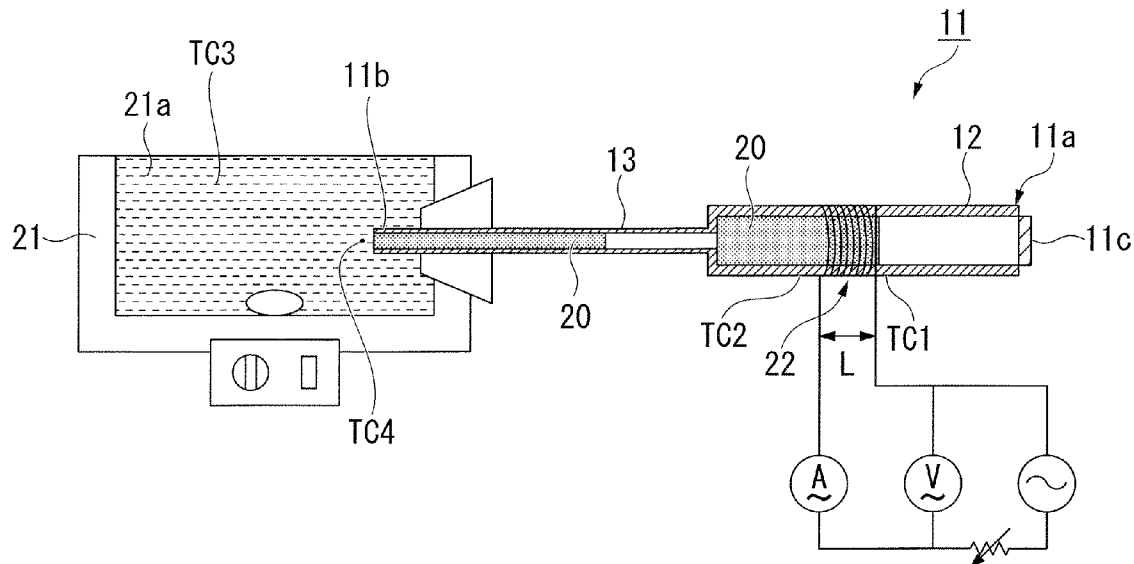


FIG. 1A

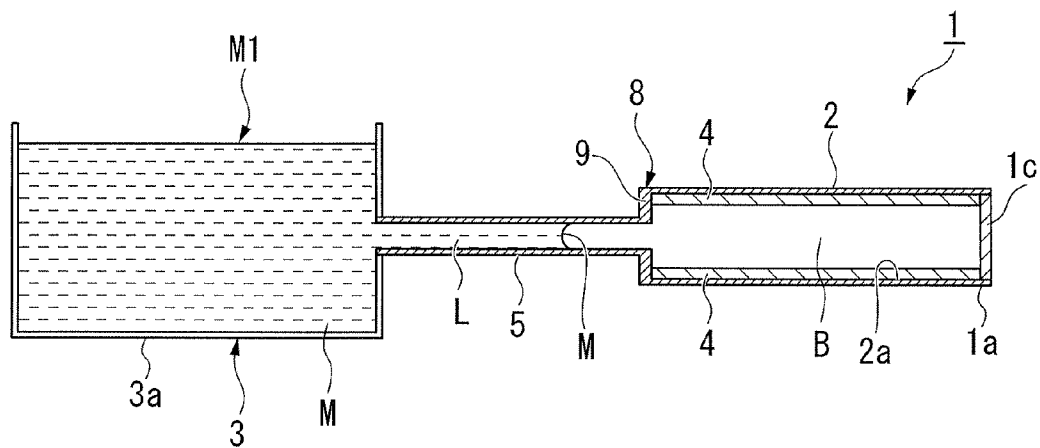


FIG. 1B

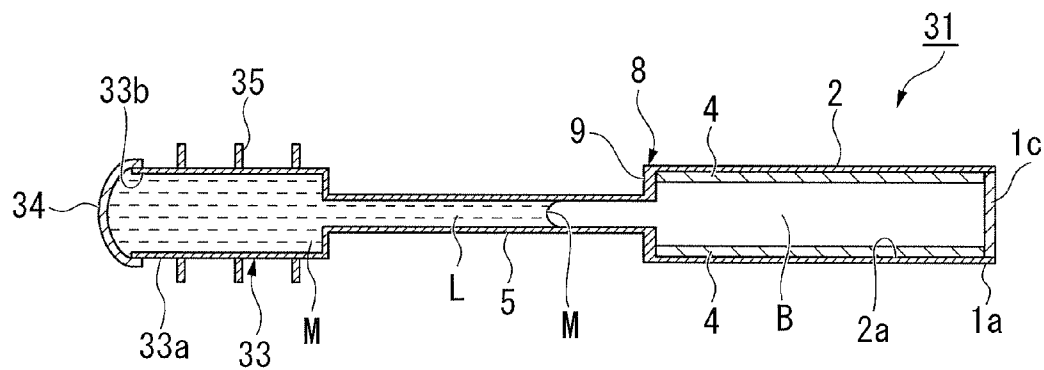


FIG. 1C

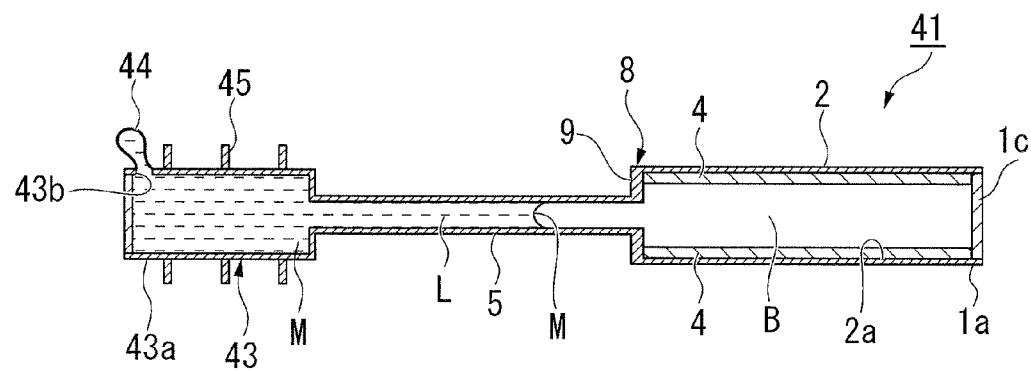


FIG. 2

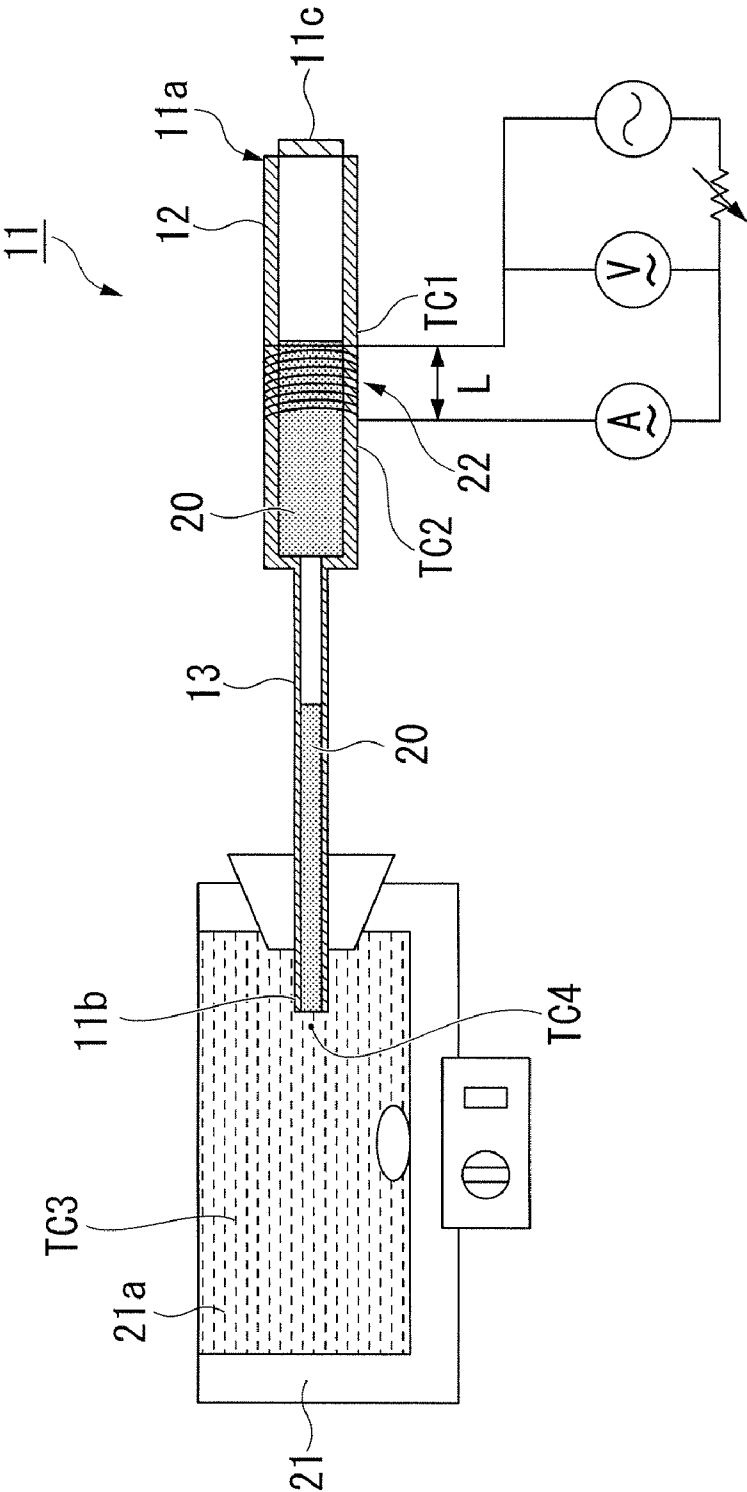


FIG. 3

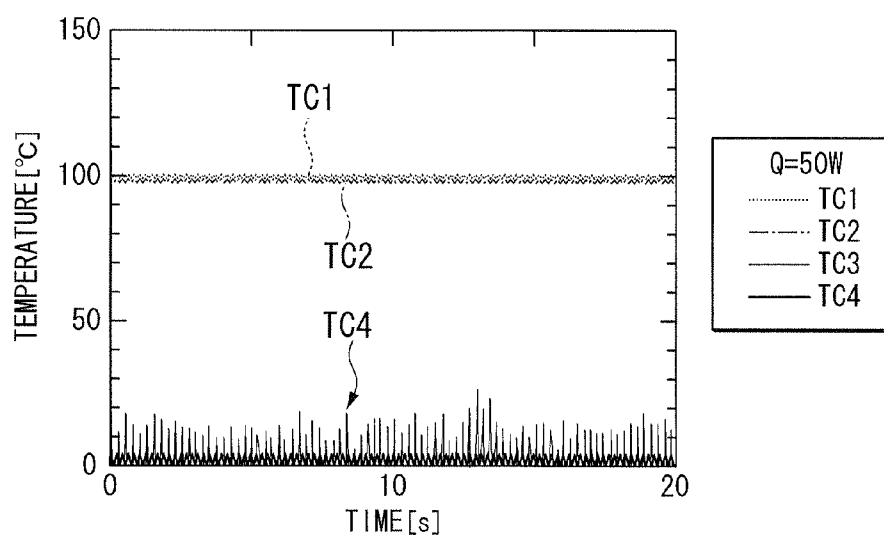


FIG. 4

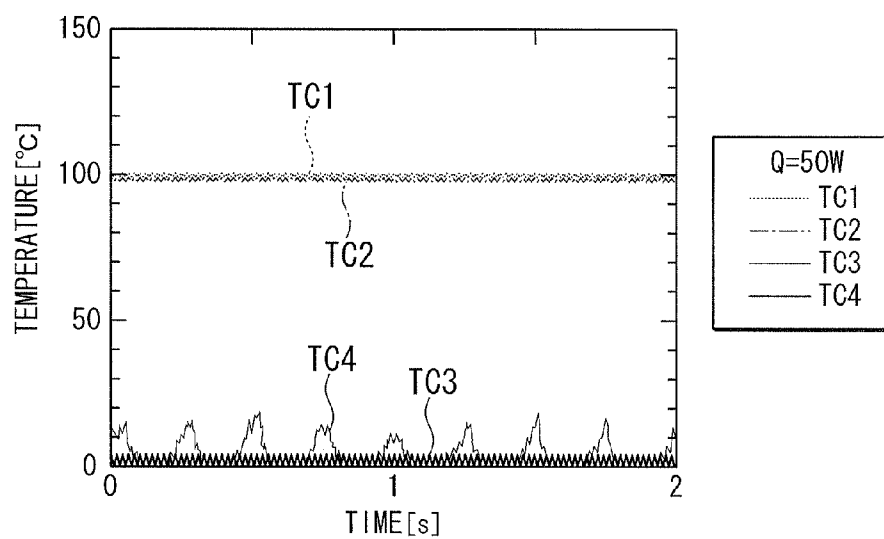


FIG. 5

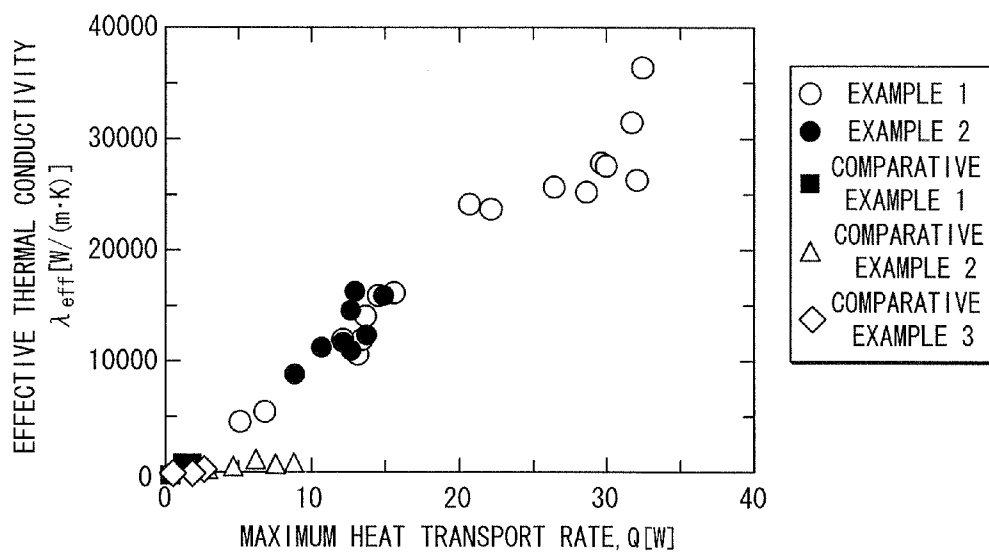
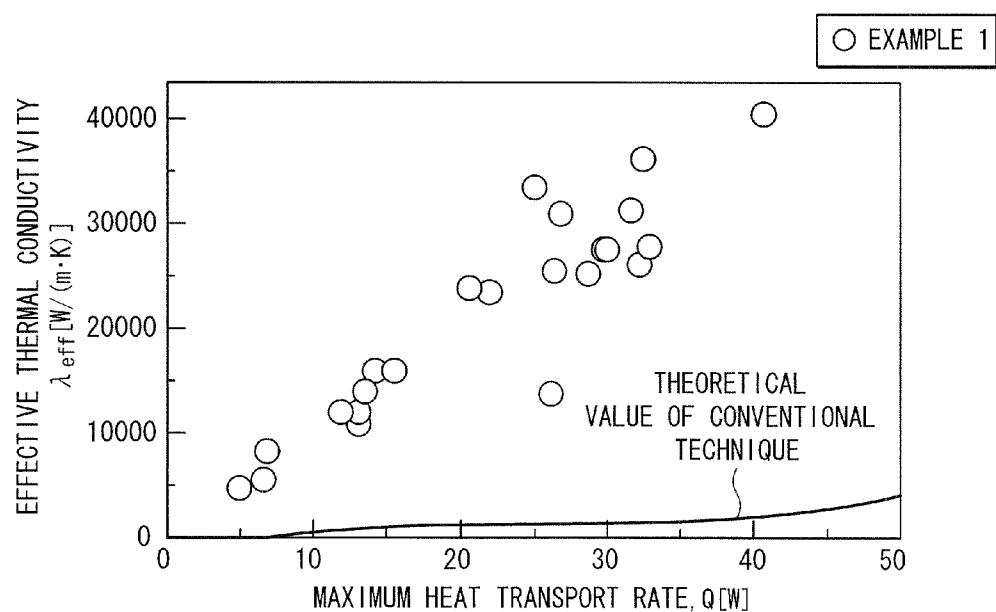


FIG. 6



SELF-EXCITED OSCILLATING FLOW HEAT PIPE

TECHNICAL FIELD

[0001] The present invention relates to a self-excited oscillating flow heat pipe.

[0002] Priority is claimed on Japanese Patent Application No. 2008-029713 filed on Feb. 8, 2008, the content of which is incorporated herein by reference.

BACKGROUND ART

[0003] In recent years, with miniaturization and high integration of electronic devices, the heat generation density of semiconductor elements has been rapidly increasing, and establishment of an efficient heat removal technique has become imperative. However, for example, when miniaturization of electronic apparatuses, such as a notebook-type personal computer, is carried out, for example, it becomes impossible to secure the space for a large-sized heat sink to be installed right above the central processing unit (CPU), which is a heat source. In such a case, it is necessary to transport generated heat to a location where the heat sink can be installed. For this reason, a wick-type heat pipe is utilized as a heat transport means under the present circumstances.

[0004] The wick-type heat pipe is built into about 90% of recent notebook-type personal computers. In such a heat pipe, the maximum heat transport rate in a case where the heat pipe has an outside diameter of about 3 mm, and is installed horizontally is about 12 W. However, the wick-type heat pipe has a problem that heat transport performance significantly declines, when the tube diameter is decreased (made small).

[0005] Thus, a self-excited oscillating flow heat pipe using a phase change with high heat transport performance even if miniaturization has recently attracted attention. However, in a meandering loop-type self-excited oscillating flow heat pipe (inside diameter of about 0.5 mm to 2 mm), which is a representative example of the above heat pipe, there are problems in that it is necessary to make a number of tubes meander, and operation of the heat pipe is difficult when horizontally installed (refer to Nonpatent Document 1).

[0006] Nonpatent Document 1 Takao Nagasaki, "Review of Pulsating Heat Pipes, Heat Transfer, Vol. 44, No. 186, 2005, pp. 13 to 17

DISCLOSURE OF THE INVENTION

Problem that the Invention is to Solve

[0007] The invention has been made in consideration of the above points, and the object thereof is to provide a self-excited oscillating flow heat pipe capable of exhibiting high heat transport performance even if the heat pipe is horizontally installed, without making the tube meander.

Means to Solve the Problems

[0008] In order to achieve the above object, the invention has adopted the following configurations.

[0009] (1) A self-excited oscillating flow heat pipe includes a heating unit having a wick therein; a cooling unit filled with a working fluid; a connection channel which rectilinearly connects the heating unit with the cooling unit, and has a smaller channel cross-sectional area than the channel cross-sectional area of the heating unit; a liquid plug protruding into the connection channel from the cooling unit and containing

the working fluid; and a vapor plug within the heating unit containing the vaporized working fluid, wherein the liquid plug oscillates self-excitedly in the connection channel.

[0010] (2) The above self-excited oscillating flow heat pipe may be configured as follows: the working fluid filled into the cooling unit has a free liquid level which is not bound to the internal pressure.

[0011] (3) The above self-excited oscillating flow heat pipe may be configured as follows: the cooling unit has an opening, and the opening is provided with an adjustment unit which adjusts the internal volume of the cooling unit.

[0012] (4) The above self-excited oscillating flow heat pipe may be configured as follows: the ratio of the cross-sectional area of the heating unit and the cross-sectional area of the connection channel is 10:1 to 2:1.

EFFECTS OF THE INVENTION

[0013] According to the self-excited oscillating flow heat pipe of the invention, it is possible to provide a self-excited oscillating flow heat pipe capable of exhibiting high heat transportation performance even if the heat pipe is horizontally installed, without making a tube meander.

BRIEF DESCRIPTION OF THE DRAWINGS

[0014] FIG. 1A is a cross-sectional schematic of a self-excited oscillating flow heat pipe related to one embodiment of the invention.

[0015] FIG. 1B is a cross-sectional schematic of a modification of the above self-excited oscillating flow heat pipe.

[0016] FIG. 1C is a cross-sectional schematic of a modification of the above self-excited oscillating flow heat pipe.

[0017] FIG. 2 is a view illustrating an experimental method of the self-excited oscillating flow heat pipe, and is a schematic showing an experimental device.

[0018] FIG. 3 is a view showing the time-change of the temperature at several locations along the heat pipe during the self-excited oscillation in the self-excited oscillating flow heat pipe of Example 1.

[0019] FIG. 4 is an enlarged view of FIG. 3.

[0020] FIG. 5 is a graph showing the relationship between heat transport rate Q and effective thermal conductivity λ_{eff} in self-excited oscillating flow heat pipes of Examples 1 and 2 and Comparative Examples 1 to 3.

[0021] FIG. 6 is a graph showing the relationship between the heat transport rate Q and the effective thermal conductivity λ_{eff} in the self-excited oscillating flow heat pipe of Example 1. FIG. 6 also shows theoretical values of the thermal conductivity of a heat pipe of a conventional technique.

DESCRIPTION OF REFERENCE NUMERALS AND SIGNS

[0022] 1: HEAT PIPE (SELF-EXCITED OSCILLATING FLOW HEAT PIPE)

[0023] 2: HEATING UNIT

[0024] 3, 33, 43: COOLING UNIT

[0025] 4: WICK

[0026] 5: CONNECTION CHANNEL

[0027] 33b, 43b: OPENING

[0028] 34, 44: ADJUSTMENT UNIT

[0029] B: VAPOR PLUG

[0030] L: LIQUID PLUG

[0031] M: WORKING FLUID

[0032] M1: FREE LIQUID LEVEL

BEST MODE FOR CARRYING OUT THE INVENTION

[0033] Hereinafter, embodiments of the invention will be described with reference to the drawings. FIGS. 1A to 1C are cross-sectional schematics of a self-excited oscillating flow heat pipe of this embodiment. In addition, FIGS. 1A to 1C are drawings for explaining the structure of a self-excited oscillating heat pipe. The sizes, thicknesses, or dimensions of shown individual sections may be different from those of an actual self-excited oscillating flow heat pipe.

[0034] The self-excited oscillating flow heat pipe 1 (hereinafter referred to as a heat pipe 1) shown in FIG. 1A is generally composed of a working fluid M, a heating unit 2 and a cooling unit 3, a wick 4 built in the heating unit 2, and a connection channel 5 which connects the heating unit 2 and the cooling unit 3 together.

[0035] In the heat pipe 1, the working fluid M flows into the connection channel 5 from the cooling unit 3 to form a liquid plug L. Additionally, in the heating unit 2, the working fluid M is vaporized to form a vapor plug B. Heat is transported as the liquid plug L oscillates self-excitedly inside the connection channel 5.

[0036] In addition, although the heat pipe 1 of this embodiment can operate in any orientation, it is preferable to install and use the pipe 1 horizontally along a longitudinal direction so that effective thermal conductivity can be made high.

[0037] The heating unit 2 is provided with a hollow portion 2a allowed to communicate with the connection channel 5. The wick 4 is arranged at the inner wall surface of the hollow portion 2a. Additionally, the cooling unit 3 is a container 3a which fills the working fluid M in the example shown in FIG. 1A. The container 3a is filled with the working fluid M. Additionally, the working fluid M forms a free liquid level M1 which faces the outside of the heat pipe 1 and is not bound to the internal pressure of the heat pipe 1. Additionally, the connection channel 5 is attached to a side wall of the container 3a. The end of the connection channel 5 on the side of the container 3a is an open end. The container 3a and the connection channel 5 are allowed to communicate with each other through this open end.

[0038] The heating unit 2 and the connection channel 5 are hollow cylindrical tubes made of ceramics, glass, or metal. One end 1a of the heating unit 2 is provided with a sealing member 1c made of ceramics, glass, or metal. Particularly, in this embodiment, the heating unit 2 and the connection channel 5 may be made of borosilicate glass, respectively.

[0039] The channel cross-sectional area of the connection channel 5 is smaller than the channel cross-sectional area of the hollow portion 2a of the heating unit 2. In the example shown in FIGS. 1A to 1C, the cross-sectional shapes of the connection channel 5 and the hollow portion 2a of the heating unit 2 are substantially circular, and the inner diameter of the connection channel 5 is smaller than the inside diameter of the hollow portion 2a of the heating unit 2. Thereby, the channel cross-sectional area of the connection channel 5 is smaller than that of the hollow portion 2a of the heating unit 2.

[0040] The ratio of the channel cross-sectional area of the hollow portion 2a of the heating unit and the channel cross-sectional area of the connection channel 5 has a preferable range of, for example, heating unit:connection channel=from 10:1 to 2:1.

[0041] When a more specific description is made of a case where the invention is applied to water cooling of a CPU of a personal computer, the inside diameter of the hollow portion 2a of the heating unit has a preferable range of 3 mm to 6 mm, and the inside diameter of the connection channel 5 has a preferable range of 0.5 mm to 3 mm.

[0042] If the channel cross-sectional area ratio, internal diameter ratio, or internal diameter of the heating unit 2 becomes smaller than the above range, since the amount of evaporation of the heating unit 2 is not sufficiently obtained, or the liquid retention capacity of the heating unit 2 is low, the heating unit is brought into a dry-out state, which is not preferable. Additionally, if the channel cross-sectional area ratio, internal diameter ratio, or internal diameter of the heating unit 2 exceeds the above range, the quantity of the fluid held within the heating unit 2 increases, and the heating time required for evaporation increases. Additionally, in a case where a low-temperature working fluid flows in from the cooling unit 3, evaporation stops, and thereby, self-excited oscillation stops, and the time until evaporation begins by reheating increases. Thus, this is not preferable.

[0043] Additionally, since the heating unit 2 and the connection channel 5 have inside diameters which are different from each other, and have thicknesses which are approximately equal to each other, the outside diameters thereof are also made different. For this reason, a flange portion 9 is formed at a joining portion 8 between the heating unit 2 and the connection channel 5. The heating unit 2 and the connection channel 5 are joined to each other via the flange portion 9. However, this configuration is just an example. As another example, for example, the internal diameters of the heating unit 2 and the connection channel 5 may be made different from each other, the external diameters of both the heating unit 2 and the connection channel 5 may be made approximately equal to each other by increasing the thickness of the connection channel 5, and the end face of the connection channel 5 may be joined to the end face of the heating unit 2.

[0044] Additionally, in the example shown in FIGS. 1A to 1C, the inside diameters of the heating unit 2 and the connection channel 5 change suddenly with the joining portion 8 as a border. However, the invention is not limited thereto. The inside diameters of the heating unit 2 and the connection channel 5 may be gradually changed in the vicinity of the joining portion 8.

[0045] The connection channel 5, as shown in FIGS. 1A to 1C, is formed in the shape of a straight line between the heating unit 2 and the cooling unit 3. Additionally, it is not necessary to form the connection channel 5 related to the invention in the shape of a loop, and the working fluid M just has to oscillate in a reciprocal manner inside the straight connection channel 5 during the operation of the heat pipe 1. Here, the term straight-line shape means a single tube structure which, unlike a conventional technique, is not bent in the shape of a loop. Although it is preferable that the connection channel 5 be substantially straight, the connection channel may have a slight curve or the like so long as the connection channel generates a self-excited oscillation.

[0046] Although the oscillation amplitude of the working fluid M during self-excited oscillation depends on the shape and size of the connection channel 5, for example, the oscillation amplitude in a case where the heating unit 2 is heated with the inside diameter of the heating unit 2 being 5 mm, the inside diameter of the connection channel 5 being 2 mm, and the length of the connection channel 4 being 150 mm,

increases so as to be about ± 25 to ± 50 mm. The lengths of the heating unit **2** and the connection channel **5** may be appropriately designed according to the above oscillation amplitude.

[0047] The wick **4** may be a conventionally well-known wick so long as the wick is capable of transporting a liquid working fluid by a capillary phenomenon. The wick **4** may be, for example, a metal net made of a material having excellent thermal conductivity, such as copper, glass wool, a cottony material such as absorbent cotton, or the like. Additionally, the wick **4** may be filled into the whole region of the heating unit **2** in the longitudinal direction. Otherwise, the wick **4** may be filled into a portion of the heating unit **2** in the longitudinal direction (for example, about $\frac{2}{3}$ of a total length in the longitudinal direction) so that one end of the wick **4** coincides with the joining portion **8** between the heating unit **2** and the connection channel **5**.

[0048] The working fluid **M** has only to be appropriately selected according to the operating temperature of the heat pipe **1**. The working fluid **M** is preferably for example pure water, an organic liquid, such as ethanol, a refrigerant, such as chlorofluorocarbon, a liquefied gas, such as ammonia, or the like.

[0049] It is preferable to completely fill a deaerated working fluid into the connection channel **5** and the heating unit **2** in advance before the operation of the heat pipe **1**. By heating the heating unit **2** of the heat pipe **1**, the working fluid **M** filled into the heating unit **2** is vaporized to form the vapor plug **B**. The working fluid **M** is extruded from the heating unit **2** by the vapor plug **B**. The working fluid **M** remains in the connection channel **5**, and forms the liquid plug **L**. Thereafter, when the working fluid reaches a steady state, evaporation and condensation of the working fluid **M** take place alternately at the meniscus **M** of the tip of the liquid plug **L**. For this reason, the liquid plug **L** performs a self-excited oscillation in the connection channel **5**. When the connection channel **5** is viewed, it can be confirmed that the meniscus **M** which becomes a gas liquid interface between the vapor plug **B** and the liquid plug **L** oscillates in a reciprocal manner inside the connection channel **5**, and thereby, the existence or nonexistence of a self-excited oscillation can be determined.

[0050] Additionally, although a portion of the liquid plug **L** is extruded to the cooling unit **3** (container **3a**) during formation of the vapor plug **B** and generation of a self-excited oscillation, since the working fluid **M** filled into the container **3a** has a free liquid level **M1**, the extruded liquid plug **L** can be absorbed.

[0051] The above heat pipe **1** includes the working fluid **M**, and the straight connection channel **5** which is arranged between the heating unit **2**, and the cooling unit **3** and through which the working fluid **M** circulates. The channel cross-sectional area of the connection channel **5** is smaller than the channel cross-sectional area of the heating unit **2**, and the heating unit **2** is provided with the wick **4**. For this reason, the effective thermal conductivity and the maximum amount of heat transport can be made markedly higher compared to the conventional self-excited oscillating flow heat pipe.

[0052] Particularly, since the heating unit **2** is provided with the wick **4**, evaporation of the working fluid **M** can be stably caused in the heating unit **2**. As a result, the effective thermal conductivity and the maximum amount of heat transport can be further made markedly higher.

[0053] Additionally, in a case where the above heat pipe **1** is horizontally installed, a self-excited oscillation can be stably maintained.

[0054] Moreover, according to the above heat pipe **1**, the heating unit **2** and the connection channel **5** are made to directly communicate with each other. For this reason, whenever the meniscus **M** of the tip of the liquid plug **L** comes to the joining portion **8** between the heating unit **2** and the connection channel **5**, a portion of the liquid is supplied to the heating unit **2**. Accordingly, the working fluid can be held in the heating unit **2** to always cause evaporation. Thereby, the working fluid can be made to stably perform a self-excited oscillation, and the effective thermal conductivity and the maximum amount of heat transport can be made high.

[0055] The above heat pipe **1** has sufficient high-efficiency simply by using one heat pipe. However, in a case where it is intended to transport a large amount of heat, the number of pipes has only to be increased if necessary, and thus, thermal design becomes easy.

[0056] Additionally, in the conventional meandering loop-type heat pipe, desired performance can not be exhibited unless the pipe is made to meander many times. However, according to the above heat pipe, the effective thermal conductivity and the maximum amount of heat transport can be made high by forming the pipe in the shape of a straight line, without making the pipe meander.

[0057] Additionally, the above heat pipe **1** can be favorably used for cooling of electronic devices, such as a CPU.

[0058] Next, another example of the heat pipe is shown in FIG. 1B. The difference between this heat pipe **31** and the heat pipe **1** shown in FIG. 1A is the configuration of the cooling unit.

[0059] A cooling unit **33** of the heat pipe **31** shown in FIG. 1B is a hollow columnar glass tube **33a** made of borosilicate glass. The inside diameter of the cooling unit **33** is greater than that of the connection channel **5**. An opening **33b** is provided at one end of the glass tube **33a**, and the opening **33b** is sealed with a thin sheet (adjustment unit) **34** made of rubber. A working fluid is filled in the cooling unit **33**.

[0060] Additionally, the outer periphery of the cooling unit **33** is provided with radiating fins **35**.

[0061] According to the heat pipe **31**, a portion of the liquid plug **L** is extruded to the cooling unit **33** during formation of the vapor plug **B** and generation of a self-excited oscillation. However, as the thin sheet **34** made of rubber provided in the cooling unit **33** deforms, the internal volume of the cooling unit substantially increases and the volume of the extruded liquid plug **L** can be absorbed. In this example, although the thin sheet made of rubber has been used as the adjustment unit, a diaphragm may be used instead.

[0062] Next, still another example of the heat pipe is shown in FIG. 1C. The difference between this heat pipe **41** and the heat pipe **31** shown in FIG. 1B is the position of the adjustment unit provided in the cooling unit.

[0063] A cooling unit **43** of the heat pipe **41** shown in FIG. 1C is a hollow columnar glass tube **43a** of which one end made of borosilicate glass is closed. The inside diameter of the cooling unit **43** is greater than that of the connection channel **5**. An opening **43b** is provided at a side surface of the glass tube **43a**. The opening **43b** is sealed with a thin sheet **44** made of rubber (adjustment unit). A working fluid is filled in the cooling unit **43**.

[0064] Additionally, an outer periphery of the cooling unit **43** is provided with radiating fins **45**.

[0065] According to the heat pipe 41, similarly to the above heat pipe 31, a portion of the liquid plug L is extruded to the cooling unit 43 during formation of the vapor plug B, and generation of a self-excited oscillation. At this time, as the thin sheet 44 made of rubber provided in the cooling unit 43 deforms, the internal volume of the cooling unit 43 substantially increases, and the volume of the extruded liquid plug L can be absorbed. In this example, although the thin sheet made of rubber has been used as the adjustment unit, a diaphragm may be used instead of this.

[0066] Hereinafter, the invention will be more specifically described by way of examples.

Observation of Self-Excited Oscillation

Example 1

[0067] Characteristics of a heat pipe were evaluated by an experimental device shown in FIG. 2.

[0068] First, a glass tube 13 used as the connection channel 5 made of borosilicate glass with an inside diameter of 2 mm and a length of 250 mm, and a glass tube 12 used as the heating unit 2 made of borosilicate glass with an inside diameter of 5 mm and a length of 150 mm were prepared, and the glass tubes 12 and 13 were fused together. Next, the wick 14 made of a copper net was mounted on the inner wall of the glass tube 12. The wick 14 was mounted at a distance of 100 mm from the fused portion. The portion mounted with the wick 14 was used as the heating unit 2. Next, sealing by a sealing member 11c of which one end 11a is made of borosilicate glass was performed. Next, an open end 11b of the glass tube 13 used as the connection channel was immersed in a water bath 21, and the insides of the glass tubes 12 and 13 were filled with pure water used as the working fluid 20. The heat pipe 11 of Example 1 was fixed up in this way.

[0069] Next, a heater 22 was mounted on the heating unit 2 of the heat pipe 11 over a length L of 50 mm, and the heat pipe 11 was substantially horizontally installed. Additionally, the portion immersed in the water bath 21 was used as the cooling unit 3 of the heat pipe 11. The temperature of cooling water 21a in the water bath 21 was maintained at 0° C. Meanwhile, the amount of heat generation of the heater 22 was set to such a degree that the temperature of the heating unit was maintained at 100° C., which is the boiling point of the pure water, and the heat pipe 11 was operated.

[0070] After the heat pipe 11 was brought into a steady state (the maximum amount of heat transport of 50 W), the surface temperature of respective units of the heat pipe 11 and the temperature of the cooling water 21a of the water bath 21 were respectively measured by a thermocouple. The results are shown in FIGS. 3 and 4.

[0071] In FIGS. 2 to 4, the temperature of a measurement location TC1 is the temperature of the heating unit 2, and is the surface temperature on the side of one end 11a of a mounting portion of the heater 22. The temperature of a measurement location TC2 is the temperature of the heating unit 2, and is the surface temperature on the side of the other end 11b of the mounting portion of the heater 22. The temperature of a measurement location TC3 is the water temperature of the cooling water 21a. The temperature of a measurement location TC4 is the water temperature immediately behind an outlet of the open end 11b.

[0072] As shown in FIGS. 3 and 4, it can be seen that TC1 and TC2 are maintained at about 100° C., and TC3 is maintained at about 0° C. Meanwhile, it can be seen that TC4 has

a periodic peak. The maximum temperature of the peak is about 10° C., and the frequency of the peak becomes 5 Hz. Additionally, the oscillation amplitude of the working fluid 20 is 100 mm (± 50 mm) at a maximum. As such, in the heat pipe 11 of Example 1, the self-excited oscillation of the working fluid 20 was observed in the steady state.

[0073] “Measurement of Heat Transport Rate Q and Effective Thermal Conductivity λ_{eff} ”

[0074] Next, the relationship between the heat transport rate Q (the amount of heat transport) and the effective thermal conductivity λ_{eff} in the heat pipe of Example 1 was investigated. In this experiment, the water temperature of the cooling water and the heating temperature of the heater were appropriately changed and measured. Additionally, the heat transport rate Q and the effective thermal conductivity λ_{eff} were calculated according to the following Expressions (1) and (2). The results are shown in FIG. 5.

[0075] In addition, in Expression (1), ρ is the density of the working fluid 20 (pure water), c_p is the specific heat at constant pressure of the working fluid 20 (pure water), V is the enclosed amount of the working fluid 20, and ΔT is the temperature increase of the water in the cooling unit during the time interval Δt .

[0076] Additionally, in Expression (2), $L_{\Phi 2}$ is the length of the sum of the total length of the connection channel and $\frac{1}{2}$ of the total length of the heating unit, T_H is the temperature of the heating unit, T_L is the water temperature of the cooling water in the water bath, and $d_{\Phi 2}$ is the inside diameter of the connection channel.

[Expression 1]

$$Q = (\rho \cdot c_p \cdot V)_{water} \cdot \frac{\Delta T}{\Delta t} \quad (1)$$

[Expression 2]

$$\lambda_{eff} = \frac{Q \cdot L_{\Phi 2}}{(T_H - T_L) \cdot \frac{\pi}{4} \cdot d_{\Phi 2}^2} \quad (2)$$

Example 2

[0077] Next, a heat pipe of Example 2 was fixed up similarly to Example 1 except that quartz glass was used as the material for a heating-side pipe and a cooling-side pipe. Then, similarly to Example 1, the relationship between the heat transport rate Q and the effective thermal conductivity λ_{eff} in the heat pipe of Example 1 was investigated. The results are shown in FIG. 5.

Comparative Example 1

[0078] Next, a heat pipe of Comparative Example 1 was fixed up similarly to Example 1 except that quartz glass was used as the material for a heating-side pipe and a cooling-side pipe, and the wick was not installed. Then, similarly to Example 1, the relationship between the heat transport rate Q and the effective thermal conductivity λ_{eff} in the heat pipe of Comparative Example 1 was investigated. The results are shown in FIG. 5.

Comparative Example 2

[0079] Next, a glass tube made of quartz glass with an inside diameter of 5 mm and a length of 400 mm was pre-

pared, and a wick made of a copper net was mounted on the inner wall surface of a hollow portion of this glass tube. Next, one end of the pipe was sealed by a sealing member. Then, the hollow portion was filled with the working fluid 20 (pure water). The heat pipe 11 of Comparative Example 2 was fixed up in this way.

[0080] Then, similarly to Example 1, the relationship between the heat transport rate Q and the effective thermal conductivity λ_{eff} in the heat pipe of Comparative Example 2 was investigated. The results are shown in FIG. 5.

Comparative Example 3

[0081] Next, a heat pipe of Comparative Example 3 was fixed up similarly to Comparative Example 2 except that a wick was not installed. Then, similarly to Example 1, the relationship between the heat transport rate Q and the effective thermal conductivity λ_{eff} in the heat pipe of Comparative Example 3 was investigated. The results are shown in FIG. 5.

[0082] (Evaluation)

[0083] As shown in FIG. 5, in the heat pipe of Embodiment 1, it can be seen that the heat transport rate shows 33 W at a maximum, and the effective thermal conductivity λ_{eff} shows 36000 W/(m·K) at a maximum. Additionally, the heat pipe of Example 2 shows comparable effective thermal conductivity λ_{eff} at the same heat transport rate as Example 1.

[0084] On the other hand, in the heat pipes of Comparative Examples 1 to 3, it can be seen that the heat transport rate becomes equal to or less than 10 W at a maximum, the effective thermal conductivity λ_{eff} becomes about 100 W/(m·K) at a maximum, and the heat transport rate Q and the effective thermal conductivity λ_{eff} significantly decline compared to Examples 1 to 2.

[0085] It can be seen from the results of Examples 1 to 2 that a self-excited oscillating flow heat pipe can be configured by joining two pipes with different inside diameters together, and enclosing a working fluid in the hollow portion of a pipe, and a self-excited oscillation can be developed even when this heat pipe is horizontally installed. In a case where two pipes with different inside diameters are joined together to form a heat pipe (Examples 1 and 2), it can be seen that the heat transport rate and the effective thermal conductivity λ_{eff} are well-correlated, and increases linearly. Additionally, in Example 1, the effective thermal conductivity was increased to about 40000 W/(m·K) at a maximum. It can be seen that the effective thermal conductivity increases to 100 times the thermal conductivity of copper (400 W/(m·K)), whose thermal conductivity is comparatively high.

[0086] Additionally, as shown in FIGS. 3 and 4, it can be seen that the temperature (TC1, TC2) of the heating unit is maintained near the boiling point of the working fluid (pure water). Since pure water was used this time, the temperature of the heating unit became about 100° C. However, if a suitable working fluid is selected according to the allowable temperature of the object to be cooled, efficient heat conduction can be realized.

[0087] In addition, in the above Example 1, the maximum value of the effective thermal conductivity was about 40000 W/(m·K), and the maximum value of the heat transport rate was about 50 W. However, these values are not limit values, and superior results may be obtained depending on the change of experimental conditions.

[0088] FIG. 6 is a comparison chart of experimental values of heat transport characteristics of the heat pipe of Example 1, and theoretical values of heat transport characteristics of the

heat pipe (dream pipe) of the conventional technique, and shows the relationship between the heat transport rate Q and the effective thermal conductivity λ_{eff} regarding individual heat pipes.

[0089] The heat pipe of this conventional technique is a heat pipe (dream pipe) of a type in which heat is axially transported by forcibly oscillating a liquid within the pipe. The effective thermal conductivity λ_{eff} of the dream pipe was calculated from the following Expressions (3) and (4).

[Expression 3]

$$\lambda_{eff} = \lambda \left\{ 1 + \frac{2.12 + \alpha}{1.14(1 + Pr^{-1})(1 + Pr^{-1/2})} \left(\frac{S}{r} \right)^2 \right\} \quad (3)$$

[Expression 4]

$$\alpha = r \sqrt{\frac{2\pi f}{\nu}} \quad (4)$$

[0090] Here, λ is the thermal conductivity of a fluid, Pr is the Prandtl number, r is the tube inside diameter, ν is the kinematic viscosity of water, f is the number of oscillations, and S is oscillation amplitude. The dream pipe of this conventional technique is of a single diameter tube-type which does not have the connection channel 5 with a smaller diameter than that of the heating unit 2.

[0091] As shown in FIG. 6, the effective thermal conductivity of the heat pipe of Example 1 is as large as about 10 times the dream pipe of the conventional technique. One of the factors of this effect is considered to be that, in the heat pipe of Example 1, the working fluid M in the glass tube 13 is replaced with a low-temperature liquid in the water bath 21 whenever the working fluid M oscillates, because the open end 11b of the glass tube 13 is opened into a water bath.

INDUSTRIAL APPLICABILITY

[0092] According to the self-excited oscillating flow heat pipe of the invention, it is possible to provide a self-excited oscillating flow heat pipe capable of exhibiting high heat transport performance even if the heat pipe is horizontally installed, without making a tube meander.

1. A self-excited oscillating flow heat pipe comprising:
 - a heating unit having a wick therein;
 - a cooling unit filled with a working fluid;
 - a connection channel which rectilinearly connects the heating unit with the cooling unit, and has a smaller channel cross-sectional area than the channel cross-sectional area of the heating unit;
 - a liquid plug protruding into the connection channel from the cooling unit and containing the working fluid; and
 - a vapor plug in the heating unit containing the vaporized working fluid,
 wherein the liquid plug oscillates self-excitedly in the connection channel.
2. The self-excited oscillating flow heat pipe according to claim 1,
 - wherein the working fluid filled in the cooling unit has a free liquid level which is not bound to internal pressure.
3. The self-excited oscillating flow heat pipe according to claim 1,
 - wherein the cooling unit has an opening, and the opening is provided with an adjustment unit which adjusts the internal volume of the cooling unit.
4. The self-excited oscillating flow heat pipe according to claim 1,
 - wherein the ratio of the cross-sectional area of the heating unit and the cross-sectional area of the connection channel is from 10:1 to 2:1.