



**Description**

## Technical Field

- 5 **[0001]** The present invention relates to a ceramics heat exchanger for transferring heat of the first fluid (high temperature side) to the second fluid (low temperature side).

## Background Art

- 10 **[0002]** Generally, driving energy of an automobile is merely about 25% of fuel combustion energy. The rest becomes an energy loss such as a cooling loss (engine cooling water of 30%), an exhaust gas loss (exhaust gas of 30%), and the like. After 2010, in the automobile field, CO<sub>2</sub> reduction has been becoming strict, and fuel efficiency requirements have been being tightened. Therefore, many automobile companies work on reduction of the exhaust gas loss, for example, exhaust heat recovery technology as a measure for reducing the energy loss to improve automobile gas mileage.

- 15 **[0003]** Patent Document 1 discloses a ceramic heat exchange element where flow passages for a heated medium are disposed from one end face to the other end face of a ceramic main body and where flow passages for a medium to be heated are formed in a direction perpendicular to the flow passages for the heated medium between the flow passages for the heated medium.

- 20 **[0004]** Patent Document 2 discloses a ceramic heat exchanger where a plurality of ceramic heat exchange elements each having flow passages for a heated fluid and flow passages for a fluid to be heated formed therein are disposed in a casing with interposing a cord-shaped sealing material made of unfired ceramic between bonding faces of heat exchange elements.

- 25 **[0005]** The Patent Document 3 discloses an exhaust system heat exchanger capable of inhibiting a cooling medium in an external cylinder from having high temperature. In addition, the Patent Document 4 discloses an exhaust gas heat recovery unit capable of relaxing thermal stress with a simple structure. Further, Patent Document 5 discloses an exhaust gas heat exchanger which is miniaturized and which can suppress costs with a structure capable of easy installation.

[Prior Art Document]

- 30 [Patent Document]

**[0006]**

- 35 [Patent Document 1] JP-A-61-24997  
[Patent Document 2] JP-B-63-60319  
[Patent Document 3] JP-A-2007-285260  
[Patent Document 4] JP-A-2007-332857  
[Patent Document 5] JP-A-2006-284165

- 40 **[0007]** Each of the Patent Documents 1 and 2 shows a structure where a heated fluid flows thereinto from the flow passages having a slit structure and where a medium to be heated flows thereinto from honeycomb structured flow passages to reduce the influence of a pressure loss of the heated fluid. However, the structure does not have good efficiency regarding the heat exchange.

- 45 **[0008]** The Patent Document 3 shows a structure where a heat exchange passage for water cooling is disposed in the periphery of a heat exchange passage for exhaust gas, it is more difficult to exchange heat in the central portion of the exhaust gas flow passages, and the heat exchange rate is low as a whole. In addition, in the Patent Document 4, the structure is constituted of an evaporation portion (first heat exchange portion), a heat-transfer fin, and a condensation portion (second heat exchange portion). However, since it exchanges heat by means of a heat-transfer fin without directly exchanging heat, the heat exchange efficiency is low. On the other hand, in the Patent Document 5, a heat exchange
- 50 core portion obtained by laminating a plurality of flat plates are formed in the route where exhaust gas passes, and a cooling liquid flow passage extending through in the thickness direction is formed. However, since exhaust gas flows through a gap between the flat plates, though the heat exchanger has high heat exchange efficiency in comparison with those of the Patent Documents 3 and 4, the contact area is not always large for heat transfer from the exhaust gas to the flat plates, and insufficient heat exchange may be caused between the exhaust gas and the cooling liquid.

- 55 **[0009]** The present invention aims to provide a heat exchanger having high heat exchange efficiency in comparison with conventional heat exchange elements, heat exchangers, and the like and realizing miniaturization, weight saving, and cost reduction and a production method thereof.

## [Summary of the Invention]

**[0010]** The present inventors found out that the aforementioned problems can be solved by a ceramics heat exchanger provided with a heat exchange element where the first fluid circulation portions for allowing a heated medium as the first fluid to circulate and the second fluid circulation portions for transferring heat to a medium to be heated as the second fluid are alternately formed as a unit. That is, according to the present invention, there are provided the following ceramics heat exchanger and production method thereof.

**[0011]**

[1] A ceramics heat exchanger comprising: first fluid circulation portions having a honeycomb structure having a plurality of cells partitioned by ceramic partition walls, extending through in an axial direction from one end face to the other end face, and allowing a heated medium as a first fluid to flow therethrough, and second fluid circulation portions being partitioned by ceramic partition walls, extending in the direction perpendicular to the axial direction, being isolated from the first fluid circulation portions by the partition walls to be capable of heat conduction, allowing a second fluid to flow therethrough, receiving the heat of the first fluid circulating in the first fluid circulation portions by means of the partition walls, and having cells for transferring heat to a medium to be heated as the second fluid; wherein the first fluid circulation portions and the second fluid circulation portions are alternately formed as a unit, the cells on the first fluid circulation portion side are smaller than the cells on the second fluid circulation portion side, and the partition walls have a density of 0.5 to 5 g/cm<sup>3</sup> and a thermal conductivity of 10 to 300 W/mK.

**[0012]**

[2] The ceramics heat exchanger according to the above [1], wherein each of the second fluid circulation portions has a slit structure having no separating partition wall or having 1 to 50 separating partition walls.

**[0013]**

[3] The ceramics heat exchanger according to the above [1] or [2], wherein a plurality of the heat exchangers are bonded together by means of a bonding material layer of heat resistant cement.

**[0014]**

[4] The ceramics heat exchanger according to any one of the above [1] to [3], wherein SiC is contained in the ceramics constituting the partition walls.

**[0015]**

[5] The ceramics heat exchanger according to any one of the above [1] to [4], wherein the ceramics constituting the partition walls is Si-impregnated SiC.

**[0016]**

[6] The ceramic heat exchanger according to any one of the above [1] to [5], wherein the first fluid is gas, and the second fluid is liquid.

**[0017]**

[7] The ceramic heat exchanger according to any one of the above [1] to [6], wherein a catalyst is loaded on wall surfaces of the first fluid circulation portions.

**[0018]**

[8] A method for manufacturing a ceramics heat exchanger comprising the steps of: forming a honeycomb structure having a plurality of cells separated by ceramic partition walls and extending through in an axial direction from one end face to the other end face by extruding a ceramic forming raw material, forming slits with regard to a part of a plurality of cell lines to extend through the partition walls forming the cells and the outer peripheral wall of the honeycomb structure in the direction perpendicular to the axial direction, and forming plugged portions plugged with a plugging member on one end face and the other end face of the cells in the cell lines where slits are formed.

**[0019]** In a ceramics heat exchanger of the present invention, attention is paid to heat and a heat exchange element which exchanges heat in exhaust heat recovery technology, and the heat exchanger realizes high heat exchange efficiency, miniaturization, weight saving, and cost reduction in comparison with a conventional heat exchange element (heat exchanger or its device).

# Brief Description of the Drawings

## [0020]

[Fig. 1] Fig. 1 is a perspective view showing an embodiment of a heat exchange element of the present invention.  
[Fig. 2A] Fig. 2A is a view showing an embodiment of an end face in the axial direction of a heat exchange element of the present invention.

[Fig. 2B] Fig. 2B is a view showing another embodiment of an end face in the axial direction of a heat exchange element of the present invention.

[Fig. 3A] Fig. 3A is a view showing an embodiment viewed from the outer peripheral wall side where slits are formed.  
[Fig. 3B] Fig. 3B is a view showing another embodiment viewed from the outer peripheral wall side where slits are formed.

[Fig. 4] Fig. 4 is a view showing an embodiment where a plurality of heat exchange elements are bonded together.

[Fig. 5] Fig. 5 is a view showing an embodiment of a ceramics heat exchanger of the present invention where a heat exchange element is disposed therein.

[Fig. 6] Fig. 6 is a view showing an embodiment of a heat exchange element where some of the partition walls have different thickness.

[Fig. 7A] Fig. 7A is a view from the inlet side of the first fluid, showing an embodiment where an end face in the axial direction of partition walls of a heat exchange element is a tapered face.

[Fig. 7B] Fig. 7B is a cross-sectional view taken along a face in parallel with the axial direction, showing an embodiment where an end face in the axial direction of partition walls of a heat exchange element is a tapered face.

[Fig. 8A] Fig. 8A is a view showing an embodiment of a heat exchange element where cells having different sizes are formed.

[Fig. 8B] Fig. 8B is a decomposition perspective view of the embodiment of Fig. 8A.

[Fig. 8C] Fig. 8C is a decomposition perspective view showing an embodiment of a circular columnar heat exchange element where cells having different sizes are formed.

[Fig. 8D] Fig. 8D is a view showing an embodiment of a heat exchange element where the size of the cells is changed.

[Fig. 8E] Fig. 8E is a view showing an embodiment of heat exchange element where the thickness of the partition walls is changed.

[Fig. 9A] Fig. 9A is a view showing an embodiment of a heat exchange element where the thickness of the partition walls is increased from the inlet side of the first fluid toward the outlet side.

[Fig. 9B] Fig. 9B is a view showing an embodiment of a heat exchange element 1 where the first fluid circulation portion is gradually narrowed from the inlet side toward the outlet side of the first fluid.

[Fig. 10A] Fig. 10A is a view showing an embodiment where the cells of a heat exchange element has a hexagonal shape.

[Fig. 10B] Fig. 10B is a view showing an embodiment where the cells of a heat exchange element has an octagonal shape.

[Fig. 11] Fig. 11 is a view showing an embodiment of a heat exchange element where R portions are formed at the corners of the cells.

[Fig. 12A] Fig. 12A is a view showing an embodiment of a heat exchange element having protruding fins in a cell.

[Fig. 12B] Fig. 12B is a view showing another embodiment of a heat exchange element having fins in a cell.

[Fig. 13A] Fig. 13A is a view showing an embodiment of a heat exchange element where a part of the cell structure is densified.

[Fig. 13B] Fig. 13B is a decomposition perspective view of the embodiment of Fig. 13A.

[Fig. 13C] Fig. 13C is a decomposition perspective view showing an embodiment of a circular columnar heat exchange element where cells having different sizes are formed.

[Fig. 13D] Fig. 13D is a view showing an embodiment of a heat exchange element where the cell density is gradually changed.

[Fig. 13E] Fig. 13E is a view showing an embodiment of a heat exchange element where the cell structure is changed by changing the wall thickness.

[Fig. 14A] Fig. 14A is a view showing an embodiment of a heat exchanger where the direction of the partition walls is offset between the front part heat exchange element and the rear part heat exchange element.

[Fig. 14B] Fig. 14B is a view showing an embodiment of a heat exchanger where the position of the partition walls

is offset between the front part heat exchange element and the rear part heat exchange element.

[Fig. 15] Fig. 15 is a view showing an embodiment of a heat exchanger where the cell density of the rear part heat exchange element is higher than that of the front part heat exchange element.

[Fig. 16] Fig. 16 is a view showing an embodiment of a heat exchanger having a constitution where the cell density of the front part heat exchange element is high on the inside and low on the outer periphery side and where the cell density of the rear part heat exchange element is low on the inside and high on the outer periphery side.

[Fig. 17A] Fig. 17A is a view showing an embodiment of a heat exchanger where a plurality of heat exchange elements are disposed, each of the heat exchange elements has two semicircular regions having different cell densities, the heat exchange elements are disposed so that the cell density distribution is different between the front part heat exchange element and the rear part exchange element.

[Fig. 17B] Fig. 17B is a decomposition perspective view of the embodiment of Fig. 17A.

[Fig. 17C] Fig. 17C is a view showing an embodiment of a heat exchange element having two prismatic columnar regions having different cell densities.

[Fig. 18A] Fig. 18A is a view showing an embodiment of a heat exchanger having a constitution where the front part heat exchange element is plugged on the outer periphery side and where the rear part heat exchange element is plugged on the inside.

[Fig. 18B] Fig. 18B is a view showing an embodiment of a heat exchanger obtained by disposing heat exchange elements where plugged prismatic column and unplugged prismatic column are combined in the front part position and the rear part position.

[Fig. 19A] Fig. 19A is a view showing an embodiment of a heat exchange element where the inlet and the outlet of the first fluid circulation portion are alternately plugged.

[Fig. 19B] Fig. 19B is an A-A cross section in Fig. 19A.

[Fig. 20] Fig. 20 is a cross section of the first fluid circulation portion, showing an embodiment where porous partition walls are formed in the first fluid circulation portion.

[Fig. 21] Fig. 21 is a view showing an embodiment of a heat exchange element where the thickness of the partition walls forming the first fluid circulation portion is gradually increased from the center toward the outer periphery in a cross section perpendicular to the axial direction.

[Fig. 22] Fig. 22 is a view showing an embodiment of a heat exchange element using a honeycomb structure where the external shape is an ellipse and where partition walls on one side is formed thick.

[Fig. 23] Fig. 23 is a view showing an embodiment where the outer peripheral wall of a honeycomb structure forming the heat exchange element is thicker than the partition walls forming the cells.

[Fig. 24] Fig. 24 is a view showing an embodiment where the external shape of the honeycomb structure forming the heat exchange element is flattened.

[Fig. 25A] Fig. 25A is a perspective view showing an embodiment where the end face on the inlet side of the first fluid is inclined.

[Fig. 25B] Fig. 25B is a perspective view showing another embodiment where the end face on the inlet side of the first fluid is inclined.

[Fig. 25C] Fig. 25C is a perspective view showing still another embodiment where the end face on the inlet side of the first fluid is inclined.

[Fig. 26] Fig. 26 is a view showing an embodiment where the end face on the inlet side of the first fluid of the honeycomb structure forming a heat exchange element is formed to have a depressed face shape.

[Fig. 27] Fig. 27 is a view showing an embodiment of a heat exchanger where an adiabatic plate have the same shape as the cells forming the first fluid circulation portion is disposed on the inlet side of the first fluid of a heat exchange element.

[Mode for Carrying out the Invention]

**[0021]** Hereinbelow, embodiments of the present invention will be described with referring to drawings. The present invention is not limited to the following embodiments, and changes, modifications, and improvements may be made as long as they do not deviate from the scope of the invention.

**[0022]** Fig. 1 is a perspective view of a heat exchange element 1 with which a ceramics heat exchanger 10 of the present invention is provided. In the heat exchange element 1, the first fluid circulation portions 5 (high temperature side) each having a honeycomb structure having a plurality of cells separated by ceramic partition walls 4, extending through in the axial direction from one end face 2 to the other end face 2, and allowing a heated medium as the first fluid to flow therethrough and the second fluid circulation portions 6 (low temperature side) each being separated by porous partition walls 4, extending through in the direction perpendicular to the axial direction, allowing the second fluid to be circulated, and transferring heat to a medium to be heated as the second fluid are alternately formed as a unit. The cells 3 on the first fluid circulation portion 5 side are smaller than the cells 3 on the second fluid circulation portion 6 side (In

the embodiment of Fig. 1, the cells 3 on the second fluid circulation portion 6 side are slits.), and the partition walls 4 have a density of 0.5 to 5 g/cm<sup>3</sup> and a thermal conductivity of 10 to 300 W/mK. Making the cells 3 on the first fluid circulation portion 5 side smaller than the cells 3 on the second fluid circulation portion 6 side is superior to making it larger in terms of heat exchange efficiency. This is because heat can be transferred to the partition walls 4 more easily when the cells 3 for the first fluid (high temperature side) are small, and the size relation of the cells 3 serves as an important element for heat transfer. That is, by constituting the cells 3 on the first fluid circulation portion 5 side to be smaller than those on the second fluid circulation portion 6 side, heat exchange efficiency can be improved.

**[0023]** Each of the first fluid circulation portions 5 preferably has a honeycomb structure having a plurality of cells 3 separated by ceramic partition walls 4 and extending through in the axial direction.

**[0024]** It is preferable that each of the second fluid circulation portions 6 has a slit structure having no separating partition wall 4 (partition wall 14 between slits (see Fig. 3B)) or having small number of (1 to 50 ) separating partition walls. The second fluid circulation portion 6 is isolated from the first fluid circulation portion 5 by a partition wall 4 to be able to transferring heat, and the second fluid circulates in it and receives heat of the first fluid circulating in the first fluid circulation portions 5 by means of the partition walls 4, thereby heat is transferred to the circulating medium to be heated, which is the second fluid.

**[0025]** In the case of honeycomb structure, when the fluid passes through a cell 3, the fluid cannot flow into another cell 3 due to the partition walls 4 and proceeds linearly from the inlet to the outlet. On the other hand, in the case of a slit structure, for example, the interior of the two slits as shown in Fig. 3B has no partition wall 4, and slits in the same line are connected to each other to allow a fluid to pass through to the slit outlet different from the inlet of the fluid. That is, the slits in the same line are connected to one another in the inside. However, in slits in different lines, fluid cannot pass through because of the partition wall 4.

**[0026]** The heat exchange element 1 of the present invention is constituted by segments each having the first fluid circulation portion 5 (high temperature side) of a honeycomb structure where the first fluid (heated medium) circulates and the second fluid circulation portion 6 (low temperature side) where the second fluid (medium to be heated) for transferring heat circulates are formed. For efficient heat exchange, it is more preferable that the first fluid circulation portion 5 has a honeycomb structure. In the honeycomb structure, a plurality of cells 3 functioning as fluid passages are partitioned and formed by the partition walls 4, and, for the cell shape, a desired shape may suitably be selected from a circle, an ellipse, a triangle, a quadrangle, other polygons, and the like. Incidentally, when a large-sized heat exchange element 1 is desired, a module structure where a plurality of segments are bonded together can be employed. On the other hand, the second fluid circulation portion 6 (low temperature side) where the second fluid (medium to be heated) circulates preferably has a slit shape (one or some in one line), and the shape of the second fluid circulation portion 6 is not particularly limited.

**[0027]** Though the shape of the segment of the heat exchange element 1 of the present invention is a quadrangular prism, the shape is not limited to this and may be another shape such as a circular cylindrical shape.

**[0028]** There is no particular limitation on the cell density (i.e., number of cells per unit cross-sectional area) of the segment, which is a heat exchange element 1 of the present invention, and design may be performed suitably in accordance with the purpose. However, it is preferably in the range from 25 to 2000 cells/sq. in. (4 to 320 cells/cm<sup>2</sup>). When the cell density is below 25 cells/sq. in., the strength of the partition walls 4, eventually, the strength of the heat exchange element 1 itself, and effective GSA (geometrical surface area) may be insufficient. On the other hand, when the cell density is above 2000 cells/sq. in., a pressure loss when a heat medium flows therethrough may increase.

**[0029]** There is no particular limitation on the thickness of the partition walls 4 (wall thickness) of the cells 3 of the honeycomb segment, which is a heat exchange element 1 of the present invention, and it may suitably be designed in accordance with the purpose. The wall thickness is preferably 50 μm to 2 mm, and more preferably 60 to 500 μm. When the wall thickness is smaller than 50 μm, the mechanical strength is decreased, and breakage may be caused by an impact or thermal stress. On the other hand, when it is larger than 2 mm, the rate of the cell capacity on the honeycomb structure side is lowered, and a defect of deterioration in heat exchange rate of permeation of a heating medium may be caused.

**[0030]** Fig. 2A is a view from an end face 2 in the axial direction of a segment, which is a heat exchange element 1 of an embodiment. As shown in Fig. 2A, the heat exchange element 1 has a plurality of cells 3 partitioned by ceramic partition walls 4 and functioning as fluid passages, and an end face 2 on one side in the axial direction is plugged in every other line. In addition, in the other end face 2, the same cells 3 as in the end face 2 on the one side are plugged in the same manner as Fig. 2A. Inside the plugged cells 3, partition walls 4 isolating the plugged cells 3 from one another are removed to form a slit shape (see Fig. 3A). That is, in the second fluid circulation portion 6, the end faces 2 in the axial direction are plugged with a plugging material to form plugged portions 13.

**[0031]** Fig. 2B is a view from an end face 2 on one side in the axial direction of a heat exchange element 1 of another embodiment. As shown in Fig. 2B, the heat exchange element 1 has a plurality of cells 3 partitioned by ceramic partition walls 4 and functioning as fluid passages, and an end face 2 on one side in the axial direction is plugged in every other line. In addition, in the other end face 2, the same cells 3 as in the end face 2 on the one side are plugged in the same

manner as Fig. 2A. Inside the plugged cells 3, partition walls 4 isolating the plugged cells 3 from one another are removed to form a slit shape (see Fig. 3A). In the unplugged cells 3, some of the partition walls 4 isolating the cells 3 from one another are removed to form large-sized cells 3. In other words, the unplugged line is formed to have a honeycomb structure where at least one partition wall 4 is present. The constitution as in Fig. 2B is effective for a segment having a long flow passage because pressure loss of a fluid is smaller. That is, a large amount of the first fluid can be allowed to flow.

**[0032]** Fig. 3A shows an embodiment viewed from the outer peripheral wall 7 side where slits are formed. As shown in Fig. 3A, in the heat exchange element 1, slits extending through from one end face 12 in the direction perpendicular to the axial direction of the outer peripheral wall 7 to the other end face 12 are formed, and the slits function as the second fluid circulation portions 6. Each of the slits is formed by removing the partition walls 4 of the cells 3 plugged in one end face 2 and the other end face 2 in the axial direction. That is, the slits are formed in the same direction as the direction of the cell lines of the plugged cells 3. The cells 3 unplugged in the end faces 2 are in the state that the partition walls 4 are formed as shown in Fig. 2A. Alternatively, as shown in Fig. 2B, there may be employed a constitution where the outer peripheral wall 7 is left and where the partition walls 4 isolating the unplugged cells 3 from one another are removed.

**[0033]** Fig. 3B shows another embodiment viewed from the outer peripheral wall 7 side where slits are formed. As shown in Fig. 3B, in the heat exchange element 1, slits extending through from one end face 12 in the direction perpendicular to the axial direction of the outer peripheral wall 7 to the other end face 12 are formed, and an inter-slit partition wall 14 separating the slits is formed in the center in the axial direction. Incidentally, the inside of the inter-slit partition wall 14 has a shape where partition walls of the cells 3 remain. This makes the structure of the heat exchange element 1 itself strong. Therefore, the heat exchange element 1 hardly breaks. When the slits are long, strength is reduced, and breakage may be caused. However, by forming the inter-slit partition wall 14, in other words, by leaving the cell wall faces, increase in strength can be planned. The slits are formed by removing the partition walls 4 of the cells 3 plugged in one end face 2 on one side and the other end face 2 on the other side in the axial direction, and the cells 3 unplugged in the end faces 2 are as shown in Figs. 2A and 2B like the aforementioned embodiment.

**[0034]** It is preferable that the segment, which is a heat exchange element 1, employs ceramics excellent in thermal resistance, in particular, silicon carbide in consideration of conductivity. However, it is not always necessary that the entire segment of the heat exchange element 1 is constituted of silicon carbide as long as silicon carbide is contained in the main body. That is, it is preferable that the heat exchange element 1 of the present invention is of conductive ceramics containing silicon carbide. As a property of a segment of the heat exchange element 1, the thermal conductivity at room temperature is preferably 10 W/mK or high, and 300 W/mK or low. However, it is not limited to the range. It is possible to use a corrosion resistant metal material such as a Fe-Cr-Al base alloy in place of the conductive ceramics.

**[0035]** The density of the partition walls 4 of the cells 3 of the heat exchange element 1 is preferably 0.5 to 5 g/cm<sup>3</sup>. In the case that it is below 0.5 g/cm<sup>3</sup>, the partition walls 4 have insufficient strength and may break due to pressure when the first fluid passes through the flow passages. In addition, when it is above 5 g/cm<sup>3</sup>, the heat exchange element 1 itself becomes heavy, and the characteristic of weight saving may be impaired. By the density in the aforementioned range, the heat exchange element 1 can be made strong. In addition, the effect in improving the thermal conductivity can be obtained.

**[0036]** In order that the heat exchange element 1 of a ceramics heat exchanger 10 of the present invention may obtain high heat exchange rate, it is preferable to use a material containing silicon carbide having high thermal conductivity as the material for the segment. However, since high thermal conductivity cannot be obtained in the case of a porous body even by silicon carbide, it is more preferable to obtain a dense body structure by impregnating the segment as the heat exchange element 1 with silicon in the process of producing the segment. By the dense body structure, high thermal conductivity can be obtained. For example, in the case of porous body of silicon carbide, it is about 20 W/mK. However, by the dense body, it can be made about 150 W/mK.

**[0037]** That is, though Si-impregnated SiC, Si<sub>3</sub>N<sub>4</sub>, SiC, or the like may be employed as the ceramic material, it is particularly desirable to employ Si-impregnated SiC in order to obtain a dense body structure for obtaining high heat exchange rate. Since the Si-impregnated SiC has a structure where a coagulation of metal silicon melt surrounds the surfaces of the SiC particles and where SiC particles are unitarily bonded together by means of metal silicon, silicon carbide is blocked from the atmosphere containing oxygen to be inhibited from being oxidized. Further, though SiC has the characteristics of high thermal conductivity and easy heat release, Si-impregnated SiC is formed densely with showing high thermal conductivity and heat resistance and shows sufficient strength as a heat transfer member. That is, the heat exchange element 1 of a Si-SiC based (Si-impregnated SiC) material shows high thermal conductivity as well as properties excellent in corrosion resistance against acid and alkali besides thermal resistance, thermal shock resistance, and oxidation resistance.

**[0038]** More specifically, in the case that the heat exchange element 1 contains a Si-impregnated SiC composite material as the main component, when the Si content specified by Si/(Si+SiC) is too small, the bonding material becomes insufficient. Therefore, bonding of adjacent SiC particles by the Si phase becomes insufficient to lower the thermal

conductivity and to have a difficulty in obtaining strength capable of maintaining the thin wall structure such as a honeycomb structure. Inversely, when the Si content is too large, the heat exchange element 1 is excessively contracted by firing due to the presence of metal silicate in the amount where the SiC particles can suitably be bonded or more to cause negative effects such as decrease in porosity and reduction in average pore diameter, which is not preferable.

Therefore, the Si content is preferably 5 to 50 mass%, more preferably 10 to 40 mass%.

**[0039]** In such Si-impregnated SiC, pores are filled with metal silicon, and there is a case that the porosity is 0 or nearly 0. It is excellent in oxidation resistance and durability and can be used for a long period of time in a high temperature atmosphere. Once it is oxidized, since an oxidation protection film is formed, oxidation deterioration is not caused. In addition, since it has high strength from ordinary temperature to high temperature, a thin and light weight structure can be formed. Further, it has high thermal conductivity which is about the same as that of copper or aluminum metal, high far-infrared emissivity, and electrical conductivity, thereby hardly having static electricity.

**[0040]** In the case that the first fluid (high temperature side) allowed to circulate in a ceramics heat exchanger 10 of the present invention is exhaust gas, it is preferable that a catalyst is loaded on the wall surfaces inside the cells 3 of the heat exchange element 1 where the first fluid (high temperature side) passes. This is because it can exchange also reaction heat (exothermic reaction) generating upon exhaust gas purification in addition to the role of exhaust gas purification. The catalyst preferably contains at least one element selected from the group consisting of noble metals (platinum, rhodium, palladium, ruthenium, indium, silver, and gold), aluminum, nickel, zirconium, titanium, cerium, cobalt, manganese, zinc, copper, zinc, tin, iron, niobium, magnesium, lanthanum, samarium, bismuth, and barium. These may be metals, oxides, and other compounds. The amount of the catalyst (catalyst metal and carrier) loaded on the first fluid circulation portion 5 of the heat exchange element 1 where the first fluid (high temperature side) passes is preferably 10 to 400 g/L. In the case of a noble metal, the amount is further preferably 0.1 to 5 g/L. When the amount of the catalyst (catalyst metal and carrier) is below 10 g/L, it may be difficult to exhibit the catalyst function. On the other hand, when the amount is above 400 g/L, pressure loss increases, and the production costs may increase. As necessary, a catalyst is loaded on the partition walls 4 of the cells 3 of the heat exchange element 1. In the case of loading the catalyst, a mask is applied on the segment, which is a heat exchange element 1, to allow the catalyst to be loaded on the heat exchange element 1. After a ceramic powder functioning as carrier microparticles is impregnated with an aqueous solution containing a catalyst component in advance, drying and firing are performed to obtain catalyst-coated microparticles. To the catalyst-coated microparticles are added a dispersion medium (water or the like) and other additives to prepare a coating liquid (slurry), and, after the slurry is coated on the partition walls 4 of the heat exchange element 1, drying and firing are performed to load the catalyst on the partition walls 4 of the cells 3 of the heat exchange element 1. Incidentally, upon firing, the mask of the heat exchange element 1 is peeled off.

**[0041]** As shown in Fig. 4, a ceramics heat exchanger 10 of the present invention may have a structure where a plurality of segments functioning as heat exchange elements 1 are bonded together with a bonding material layer 8 of heat resistant cement. A large size can be obtained by modularization by bonding segments functioning as the heat exchange elements 1 of the present invention. The segments are bonded by the use of heat resistant cement. The heat resistant cement plays a role of an adhesive and is applied to the periphery of the face where the inflow port and the outflow port of the second inflow circulation portion 6 are formed of the outer peripheral walls 7 of the segments to bond segments together. In this case, the bonding material is applied lest the second fluid circulation portion 6 should be closed by the heat resistant cement.

**[0042]** As shown in Fig. 5, a ceramics heat exchanger 10 of the present invention includes a heat exchange element 1 and a heat exchange element-holding container 11 having the heat exchange element 1 therein. Though the material of the heat exchange element-holding container 11 is not particularly limited, the container is preferably constituted of a metal having good workability (e.g. stainless steel). The material for the constitution including a connection pipe is not particularly limited.

**[0043]** Fig. 6 shows another embodiment of a heat exchange element 1 and is a view from the end face 2 on the one side, which is the first fluid inlet side of a heat exchange element 1. As shown in Fig. 6, the heat exchange element 1 has a plurality of cells 3 separated by ceramic partition walls 4, extending through in the axial direction from one end face 2 on one side to the end face 2 on the other side (see Fig. 1), and allowing the heating element functioning as the first fluid to circulate therethrough. Some of the partition walls 4 forming the cells 3 have different thickness (wall thickness). That is, the heat exchange element 1 of Fig. 1 is an embodiment where the partition walls 4 have thick portions and thin portions. The constitution other than the thickness of the partition walls 4 is the same as the heat exchange element 1 of Fig. 1 and is formed in such a manner that the second fluid circulates perpendicularly to the first fluid. By such a difference in wall thickness, pressure loss can be reduced. Incidentally, the thick portions and the thin portions of the walls may be disposed regularly or at random as shown in Fig. 6, and similar effects can be obtained.

**[0044]** Fig. 7A shows an embodiment where an end face 2 of the partition wall 4 of the heat exchange element 1 is a tapered face 2t and is a view of the end face 2 on one side of the heat exchange element 1 from the first fluid inlet side. Fig. 7B shows an embodiment where an end face 2 of the partition wall 4 of the heat exchange element 1 is a tapered face 2t and is a cross sectional view taken along the face in parallel with the axial direction. As shown in Figs. 7A and

7B, the heat exchange element 1 has a plurality of cells 3 partitioned by ceramic partition walls 4 and extending through in the axial direction from one end face 2 to the other end face 2 (see Fig. 1), and allowing a heated medium functioning as the first fluid to circulate therethrough with the end face 2 being a tapered face 2t. By making the end portion of the partition wall 4 of the inlet of the first fluid have a tapered face 2t, the inflow resistance of the fluid is decreased to reduce pressure loss.

**[0045]** Fig. 8A is a view of the end face 2 viewed from the first fluid inlet side of the heat exchange element 1, showing an embodiment where the cells 3 having different sizes are formed. Fig. 8B is a decomposition perspective view of the embodiment of Fig. 8A. Since the first fluid flowing the central portion has a high flow rate, the temperature is high, the volume is large, and the pressure loss is large. Therefore, by making the cells 3 in the central portion large, the pressure loss can be reduced. In the embodiments shown in Figs. 8A and 8B, a honeycomb structure having large-sized cells 3 partially including plugged portions 13 is disposed in the central portion, and the outer peripheral wall is provided with a fluid sealing material 19 in the end portion thereof. Four honeycomb structures 4 having small-sized cells partially including plugged portions 13 are provided to surround the outer periphery of the honeycomb structure in the central portion. It allows the second fluid to flow from the second fluid circulation portion 6 of the outside honeycomb structure to the second fluid circulation portion 6 of the inside (central portion) honeycomb structure by the fluid sealing material 19.

**[0046]** Fig. 8C is a decomposition perspective view showing an embodiment of a circular cylindrical heat exchange element 1 having the cells 3 having different sizes and partially including plugged portions 13. Each of the inside circular columnar honeycomb structure and the outside circular honeycomb structure has the first fluid circulation portion 5 and the second fluid circulation portion 6 formed therein (Cells 3 are plugged similarly to, for example, Fig. 2A, and each circulation portion is formed.), and a fluid sealing material 19 is unitarily provided between the inside circular cylindrical honeycomb structure and the outside cylindrical honeycomb structure. (Fig. 8C shows the inside honeycomb structure and the outside honeycomb structure in the decomposed state.) The fluid sealing member 19 enables the second fluid to flow from the second fluid circulation portion 6 of the outside honeycomb structure to the second fluid circulation portion 6 of the inside honeycomb structure.

**[0047]** Fig. 8D shows an embodiment where the cells 3 have different sizes and is a view of an end face 2 from the inlet side of the first fluid. The embodiment is formed so that the size of the cells 3 gradually increases from the right side to the left side of the figure. The right side of the figure is the inlet side of the second fluid, and the cells 3 are small on the inlet side of the second fluid inlet side while the cells 3 are large on the outlet side. In the heat exchanger 1 shown in Fig. 5, when the first fluid circulation portion is formed as Fig. 8D with sending the second fluid from the right side to the left side of Fig. 8D, since the temperature of the second fluid is high in the downstream side (left side of Fig. 8D) of the second fluid, the temperature of the first fluid flowing on the down stream side of the second fluid becomes high, and pressure loss is large. However, by enlarging the cells 3 on the down stream side of the second fluid, pressure loss can be reduced. Fig. 8E shows an embodiment where the thickness of the partition walls 4 of the cells 3 is changed and is a view of the end face 2 on the inlet side of the first fluid. The partition walls 4 are formed so that the thickness gradually reduces from the right side to the left side of the figure. The right side of the figure is the inlet side of the second fluid, and, by thinning the partition walls 4 of the cells 3 on the downstream side of the second fluid, the pressure loss can be decreased like the case of Fig. 8D.

**[0048]** Fig. 9A is a cross-sectional view taken along a cross section in parallel with the axial direction, showing an embodiment of a heat exchange element 1 where the thickness of the partition walls 4 is increased from the inlet side of the first fluid toward the outlet side (from the upstream side to the downstream side). In addition, Fig. 9B shows an embodiment of a heat exchange element 1 where the first fluid circulation portions 5 are gradually narrowed from the inlet side of the first fluid toward the outlet side (from the upstream side to the downstream side). In the first fluid circulation portions 5, temperature of the first fluid falls, and heat transfer is reduced by the volume contraction of the first fluid as it flows toward the downstream side. By narrowing the first fluid circulation portions 5, contact is improved, and heat transfer between the first fluid and the wall faces of the partition walls can be increased.

**[0049]** In a heat exchange element 1 shown in Fig. 1, the shape of the cells 3 functioning as the first fluid circulation portion 5 may be made hexagonal as shown in Fig. 10A. In addition, as shown in Fig. 10B, the shape of the cells 3 of the first fluid circulation portion 5 may be made octagonal. By such a shape, since the angle of the corners is widened, stagnation or the like of the fluid is reduced, and boundary film thickness (temperature boundary layer thickness of the first fluid) can be reduced to raise the heat transfer coefficient between the first fluid and the wall faces of the partition walls.

**[0050]** In addition, in a heat exchange element 1 shown in Fig. 1, as shown in Fig. 11, the R portion 3r may be formed by making the corner portion of the cell 3 functioning as the first fluid circulation portion 5 have an R shape. By such a shape, since the angle of the corners is widened, stagnation or the like of the fluid is reduced, and boundary film thickness can be reduced to raise the heat transfer coefficient between the first fluid and the wall faces of the partition walls.

**[0051]** Further, in the heat exchange element 1 shown in Fig. 1, as shown in Figs. 12A and 12B, there may be employed a fin structure having fins 3f protruding in the cells 3 functioning as the first fluid circulation portion 5. The fins 3f are formed so as to extend in the axial direction (direction where the first fluid flows) on wall faces of partition walls 4 forming the cell 3, and the shape of each fin 3f may be a plate-like shape, a semispherical shape, a triangle, a polygon, or the

like. This enables not only to increase the conductive area, but also thin the boundary film by disarranging the flow to raise the heat transfer coefficient between the first fluid and the wall faces of the partition walls. Incidentally, the fins 3f may be formed only in unplugged cells 3 or in plugged cells 3.

**[0052]** Fig. 13A shows an embodiment of a heat exchange element 1 where a part of the cell structure is dense. Fig. 13B is a decomposition perspective view of the embodiment of Fig. 13A. The first fluid flowing in the cells 3 in the central portion of the heat exchange element 1 has high temperature because of a high flow rate. It is preferable to narrow the cells in the central portion of the heat exchange element 1 and to widen the cells 3 in the external side portion of the heat exchange element 1. In the embodiment shown in Figs. 13A and 13B, a honeycomb structure having small-sized cells 3 partially including plugged portions 13 is disposed in the central portion, fluid sealing materials 19 are provided in the end portions of the outer peripheral walls, and four honeycomb structures 4 having large-sized cells 3 partially including plugged portions 13 are provided so as to surround the outer periphery of the honeycomb structure in the central portion. The fluid sealing materials 19 enable the second fluid to flow from the second fluid circulation portion 6 of the outside honeycomb structure to the second fluid circulation portion 6 of the inside (central portion) honeycomb structure.

**[0053]** Fig. 13C is a decomposition perspective view showing an embodiment of a circular cylindrical heat exchange element where cells 3 partially including plugged portions 13 and having different sizes. Each of the inside circular columnar honeycomb structure and the outside circular honeycomb structure has the first fluid circulation portion 5 and the second fluid circulation portion 6 formed therein (Cells 3 are plugged similarly to, for example, Fig. 2A, and each circulation portion is formed.), and a fluid sealing material 19 is unitarily provided between the inside circular cylindrical honeycomb structure and the outside cylindrical honeycomb structure. (Fig. 13C shows the inside honeycomb structure and the outside honeycomb structure in the decomposed state.) The fluid sealing member 19 enables the second fluid to flow from the second fluid circulation portion 6 of the outside honeycomb structure to the second fluid circulation portion 6 of the inside honeycomb structure.

**[0054]** Fig. 13D is an embodiment where a part of the cell structure is densely formed, viewed from the end face 2 on the inlet side of the first fluid. The structure is formed so that cell density may gradually increase from the right side of the figure to the left side. In the cells 3 functioning as the first fluid circulation portion 5, the cell density on the second fluid inlet side is low, and the cell density on the outlet side is high. In addition, Fig. 13E shows an embodiment of a heat exchange element 1 where the cell structure is changed by changing the thickness (wall thickness) of the partition walls 4. The cells 3 functioning as the first fluid circulation portions 5 have low cell density on the inlet side of the second fluid on the right side of the figure and high cell density of the outlet side on the left side of the figure. In the heat exchanger 1 shown in Fig. 5, by forming the first fluid circulation portion 5 as in Fig. 13D (or Fig. 13E) to allow the second fluid to flow from the right side to the left side of Fig. 13D (or Fig. 13E), the first fluid flowing on the second fluid downstream side (left side of Fig. 13D (or Fig. 13E)) has high temperature because the second fluid has high temperature and has high pressure loss. However, by raising the cell density on the downstream side of the second fluid of the cells 3 of the first fluid circulation portion 5, the conductive area can be increased. In addition, by increasing the thickness of the partition walls 4, the total heat transfer amount can be increased.

**[0055]** Fig. 14A shows an embodiment of a heat exchanger 10 where a plurality of heat exchange elements 1 are disposed in series in the direction where the first fluid flows and where the direction of the partition walls 4 forming the cells 3 of the front part (upstream side) heat exchange element 1 and the direction of the partition walls 4 forming the cells 3 of the rear part (downstream side) heat exchange element 1 are offset. In the present embodiment, cells 3 are plugged similarly to the case of, for example, Fig. 2A with each circulation portion being formed. Fig. 14B shows an embodiment of a heat exchanger 10 with the positions of the partition walls 4 being offset. Thus, by allowing the heat exchanger 10 to have a structure where the directions, positions, and the like of partition walls 4 of a plurality of the heat exchange elements 1 are offset, the flow of the fluid can be disarranged at the sites where the positions of the walls are offset, and boundary film thickness can be reduced to raise the heat transfer coefficient between the first fluid and the wall faces of the partition walls.

**[0056]** Fig. 15 shows an embodiment of a heat exchanger 10 having a constitution where a plurality of heat exchange elements 1 are disposed in series in the direction where the first fluid flows and where the cell density of the rear part (downstream side) heat exchange element 1 is higher than that of the front part (upstream side) heat exchange element 1. In the present embodiment, cells 3 are plugged similarly to the case of, for example, Fig. 2A with each circulation portion being formed. In the first fluid circulating in the first fluid circulation portion 5, temperature falls as it flows downstream, and heat transfer is reduced by volume contraction of the first fluid. In the present embodiment, by the disposition where the rear part (downstream) heat exchange element 1 has higher cell density, conductive area is increased to improve heat transfer between the first fluid and the wall faces of the partition walls 4.

**[0057]** Fig. 16 shows an embodiment of a heat exchanger 10 where a plurality of heat exchange elements 1 having regions having different cell density distributions are disposed in series in a direction where the first fluid flows. Each of the heat exchange elements 1 has a constitution shown by any of Figs. 8C and 13C. Specifically, the embodiment has a constitution where two regions of the inside (center side) and the outer periphery side in a peripheral direction are

formed and where the cell density of the front part (upstream) heat exchange element 1 is high in the inside and low in the outer periphery side while the cell density of the rear part (downstream) heat exchange element 1 is low in the inside and high in the outer periphery side. By allowing the fluid flow to be disarranged by the cell structure where the cell density distribution is changed between the front part and the rear part, boundary film thickness can be reduced to raise the heat transfer coefficient between the first fluid and the wall faces of the partition walls 4. Incidentally, the number of regions having different cell densities is not limited to two and may be three or more.

**[0058]** Fig. 17A shows an embodiment of a heat exchanger 10 where a plurality of heat exchange elements 1 each having regions partially including plugged portions 13 and having different cell density distributions formed therein are disposed in series in the direction where the first fluid flows. Fig. 17B is a decomposition perspective view of the embodiment of Fig. 17A. In the present embodiment, cells 3 in each region are plugged similarly to, for example, the case of Fig. 2A with each circulation portion being formed. Specifically, two semicircular regions are formed, and, upon disposing honeycomb structures as the heat exchange elements 1 in series, the cell density distributions are changed between the left and the right (or the top and the bottom) of the front part (upstream) and rear part (downstream) honeycomb structures. The embodiment has a constitution where the cell density of the front part heat exchange element 1 is high on one side (right side in the figure) and low in the other side (left side in the figure), and the cell density of the rear part heat exchange element 1 is high on the other side (left side in the figure) and low in the one side (right side in the figure). That is, since the cell density in the corresponding portions is different between the front part heat exchange element and the rear part heat exchange element, in other words, because of a cell structure where the cell density distribution is changed between the front part one and the rear part one, the fluid flow can be disarranged, and boundary film thickness can be reduced to raise the heat transfer coefficient between the first fluid and the wall faces of the partition walls 4. As shown in Fig. 17C, there may be employed a heat exchange element 1 having a honeycomb structure where quadrangular two regions are formed. By the constitution where the cell density distribution is changed between the left and the right (or the top and the bottom) of the front part (upstream) and rear part (downstream) honeycomb structures upon distributing the heat exchange elements 1 shown in Fig. 17C in series as in Fig. 17A, the fluid flow can be disarranged, and the heat transfer coefficient can be raised.

**[0059]** Fig. 18A shows an embodiment of a heat exchanger 10 having a constitution where a plurality of heat exchange elements 1 are disposed in series in the direction where the first fluid flows and where the flow passages of the first fluid are changed between the front part one and the rear part one. Specifically, two regions of the inside (center side) and the outer periphery side are formed in a peripheral direction, the front part heat exchange element 1 is entirely plugged in the outer periphery side and partially plugged in the inside (Cells 3 in the inside are plugged similarly to, for example, the case of Fig. 2A with each circulation portion being formed.), and the rear part heat exchange element 1 is entirely plugged in the inside and partially plugged in the outer periphery side (Cells 3 in the outer periphery side are plugged similarly to, for example, the case of Fig. 2A with each circulation portion being formed.) By such constitution, the fluid flow can be disarranged, and boundary film thickness can be reduced to raise the heat transfer coefficient between the first fluid and the wall faces of the partition walls. Fig. 18B is a view showing an embodiment of a heat exchanger where heat exchange elements 1 each obtained by combining an entirely plugged prismatic column and a partially unplugged prismatic column are disposed in the front part and rear part portions. The bottom region of the front part is completely plugged, and the upper region of the rear part is completely plugged. The constitution enables the flow of the first fluid to change.

**[0060]** Fig. 19A shows an embodiment of a heat exchange element 1 where the inlets and the outlets of the first fluid circulation portions 5 are alternately plugged. Fig. 19B is an A-A cross-sectional view in Fig. 19A. The material for the partition walls 4 is varied depending on the place of the partition walls 4, and the constitution is made so that the first fluid flowing in from the inlet passes the partition walls 4 and flows out from the outlet. By the constitution, heat collection of the first fluid is performed not on the wall face but inside the porous partition walls 4. Since heat can be collected not by the two-dimensional surface but three-dimensionally, the conductive area can be increased.

**[0061]** Fig. 20 shows an embodiment where porous walls 17 are formed in the first fluid circulation portion 5 as the first fluid passage. Fig. 20 is a cross-sectional view of the first fluid circulation portion 5. The porosity of the porous walls in the first fluid circulation portion 5 is higher than that of the partition walls 4 between the first fluid circulation portion 5 and the second fluid circulation portion 6. Therefore, in the present embodiment, the first fluid passes through the porous walls 17 and is discharged from the outlet. Since heat can be collected not by the two-dimensional surface but three-dimensionally, the conductive area can be increased even in the same volume. Alternatively, the heat exchange element 1 can be miniaturized.

**[0062]** Fig. 21 shows an embodiment of a heat exchange element 1 where the thickness (wall thickness) of the partition walls 4 forming the first fluid circulation portion 5 is gradually increased from the center toward the outer periphery in a cross section perpendicular to the axial direction. In the case of the heat exchange elements having the same size, the thicker the wall is, the higher the fin efficiency is. By thickening the path for transferring heat collected from the cell central portion, heat conduction inside the wall can be increased.

**[0063]** Fig. 22 shows an embodiment of a heat exchange element 1 employing a honeycomb structure having an

external shape of an ellipse. In the present embodiment, the partition walls 4 extending in the short axial direction is formed to be thick. Since the fin efficiency is high as the partition walls 4 became thick, thick walls are disposed on the side perpendicular to the second fluid so that the heat of the first fluid can be transferred to the second fluid to raise the entire thermal conduction. In addition, pressure loss can be reduced in comparison with increase of the thickness in the entire portions. The shape of the heat exchange element 1 may be rectangle.

**[0064]** Fig. 23 shows an embodiment where the outer peripheral wall 7 of a honeycomb structure forming the heat exchange element 1 is thicker than the partition walls 4 forming the cells 3. By making the outer peripheral wall 7 thicker than the cells 3 in the central portion, strength of the structure can be enhanced. In the present embodiment, the cells 3 are plugged similarly to, for example, the case of Fig. 2A with each circulation portion being formed.

**[0065]** Fig. 24 shows an embodiment where the external shape of the honeycomb structure forming the heat exchange element is flattened. The conductive path can be made short in the short axial portion in comparison with a circle, and it has small waterway pressure loss in comparison with the case of making the external shape of the honeycomb structure a corner structure.

**[0066]** Figs. 25A to 25C show an embodiment where end faces 2 on the inlet side of the first fluid of the honeycomb structure are inclined. By inclining the inlet, the area where the high temperature portion of the first fluid is brought into contact becomes wider to increase the entire conductive area. It is also possible to make the end faces on the outlet side inclined, and, in this case, the pressure loss can be reduced.

**[0067]** Fig. 26 shows an embodiment where the end face 2 on the inlet side of the first fluid of the honeycomb structure forming a heat exchange element 1 is formed to have a depressed face shape. By making the inlet of the first fluid depressed, the high temperature portion of the first fluid is extended backward to raise the heat exchange efficiency of the honeycomb backward portion with the second fluid. In addition, by making the depression, the thermal stress at the surface can be made a compression stress to be able to maintain high rupture strength.

**[0068]** Fig. 27 shows an embodiment of a heat exchanger 10 where an adiabatic plate 18 has the same shape as the cells 3 forming the first fluid circulation portion 5 is disposed on the inlet side of the first fluid of a heat exchange element 1. Since the opening ratio of the inlet on the first fluid side is small, in the case of disposing no adiabatic plate, when the first fluid is brought into contact with the end face on the inlet side, heat is lost at the inlet wall face. Disposing an adiabatic plate having the same shape in accordance with the inlet allows the first fluid to flow into the honeycomb with maintaining the heat to prevent the heat of the first fluid from being lost. In the present embodiment, cells 3 are plugged similarly to, for example, the case of Fig. 2A with each circulation portion being formed.

**[0069]** There is no particular limitation on the heated medium as the first fluid being circulated in a ceramics heat exchanger 10 of the present invention having a constitution as described above as long as it is a medium having heat, such as gas or liquid. An example of gas is automobile exhaust gas. In addition, regarding the medium to be heated as the second fluid which take heat from (exchange heat with) the heated medium, there is no particular limitation on the medium as long as the temperature is lower than that of the heated medium, such as gas or liquid. Though water is preferable in consideration of handling, it is not particularly limited to water.

**[0070]** As described above, since the heat exchange element 1 has high heat conductivity, and there is a plurality of sites functioning as fluid passages by the partition walls 4, high heat exchange rate can be obtained. Therefore, the entire heat exchange element 1 can be miniaturized, and it can be mounted on an automobile. In addition, pressure loss is small with respect to the first fluid (high temperature side) and the second fluid (low temperature side).

**[0071]** Next, a method for manufacturing a ceramics heat exchanger 10 of the present invention is described. In the first place, a ceramic forming raw material is extruded to form a honeycomb structure where a plurality of cells 3 partitioned by ceramic partition walls 4 and extending through in an axial direction from one end face 2 to the other end face 2 are partitioned and formed. Then, regarding a part of the cell lines, slits are formed so as to extend through the partition walls 4 forming the cells 3 and the outer peripheral wall 7 of the honeycomb structure in the direction perpendicular to the axial direction, and plugged portions 13 plugged with plugging members are formed on one end face 2 each of and the other end face 2 of each of the cells 3 in the cell lines where the slits are formed to manufacture a heat exchange element 1.

**[0072]** Specifically, the manufacturing can be performed as follows. After kneaded clay containing a ceramic powder is extruded into a desired shape, drying and firing are performed to obtain a honeycomb structure segment. By this, there can be obtained a honeycomb structure segment (rectangular parallelepiped) where a plurality of cells 3 functioning as gas flow passages are partitioned and formed by the partition walls 4.

**[0073]** Though the aforementioned ceramics can be employed as the material for the heat exchange element 1, for example, in the case of manufacturing a segment containing Si-impregnated SiC composite material as the main component, in the first place, predetermined amounts of a C powder, a SiC powder, a binder, and water or an organic solvent are kneaded and formed to obtain a formed article having a desired shape. Next, the formed article is put in pressure-reduced inert gas or vacuum in a metal Si atmosphere to impregnate the formed article with metal Si.

**[0074]** Incidentally, also, in the case of employing  $\text{Si}_3\text{N}_4$ , SiC, and the like, kneaded clay of a forming material is formed, and the kneaded clay is subjected to extrusion forming in a forming step to form a honeycomb-shaped formed

article having a plurality of cells 3 partitioned by partition walls 4 and functioning as exhaust gas passages. The article is dried and fired to obtain a heat exchange element 1 of a segment formed as a honeycomb structure (honeycomb structure segment).

**[0075]** Next, the honeycomb structure segment manufactured above is cut out to form slits in every other cell line on the side of the honeycomb structure segment. Then, with respect to the cut-out face (end face 2) on the honeycomb structure side, plugging on each cell line having a slit is performed. The plugging material preferably has the same composition as that of the honeycomb structure segment. When the segment is of silicon carbide (SiC), the plugging material is preferably of silicon carbide. Then, the plugged honeycomb structure (segment) is fired in a hydrogen atmosphere to manufacture a segment as a heat exchange element 1.

**[0076]** As described above, a side face (outer peripheral wall 7) of the honeycomb-structured segment manufactured by extrusion forming as described above is subjected to slit-working to form the second fluid circulation portions 6, and the first fluid circulation portions 5 are subjected to plugging for manufacturing at low costs. When the size of the heat exchange element 1 is increased, modularization is easy.

**[0077]** Since a heat exchange element 1 of the present invention has a cross-flow structure of the first fluid (high temperature side) and the second fluid (low temperature side) and shows high heat exchange efficiency between the first fluid (high temperature side) and the second fluid (low temperature side) in comparison with conventional ones, the heat exchanger 10 itself can be miniaturized. Further, since manufacturing from a unitary type by extrusion forming is possible, costs can be reduced. The heat exchange element 1 can suitably be used in the case that the first fluid is gas and that the second fluid is liquid. For example, it can suitably be used for exhaust heat recovery or the like to improve automobile gas mileage.

#### Example

**[0078]** Hereinbelow, the present invention will be described in more detail on the basis of Examples. However, the present invention is by no means limited to these Examples.

#### (Manufacturing of segment of heat exchange element)

**[0079]** After the kneaded clay containing a ceramic powder was extruded to have a desired shape, it was dried and fired to manufacture a heat exchange element 1 of silicon carbide segment having a main body size of 33×33×60 mm.

#### (Examples 1 to 5, Comparative Examples 1 to 3)

**[0080]** The structures of the segments of the heat exchange elements 1 of Examples 1 to 5 and Comparative Examples 1 to 3 are as in Table 1. Incidentally, no catalyst was loaded on any of the Examples and Comparative Examples. In addition, the "number of the partition walls" of the first fluid circulation portion 6 shows the number of the partition walls in one line (For example, the numbers of the partition walls are "6" in Fig. 2A and "2" in Fig. 2B.).

#### (Heat exchange element-holding container)

**[0081]** As the outside container for the heat exchange element 1, a stainless steel heat exchange element-holding container 11 was used. Pipes are provided on the heat exchange element-holding container 11 in accordance with the cross-flow structure of the heat exchange element 1. Incidentally, the two routes are completely partitioned lest the first fluid and the second fluid should be mixed together.

#### (First fluid and second fluid)

**[0082]** The inlet temperature and the flow rate of the first fluid and the second fluid were entirely the same. As the first fluid, nitrogen gas (N<sub>2</sub>) at 350°C was used. As the second fluid, water was used.

#### (Test method)

**[0083]** The nitrogen gas had a SV (space velocity) of 50,000 h<sup>-1</sup> with respect to the heat exchange element 1. Model gas was allowed to flow into the first fluid circulation portions 5 of the heat exchange element 1, and (cooled) water was sent into the second fluid circulation portions 6. The (cooled) water had a flow rate of 5 L/min. Though the heat exchanger 10 of Comparative Example 1 has a structure different from those of the heat exchangers 10 of Examples 1 to 3, the test conditions such as flow rate of the first fluid and the second fluid were entirely the same. Incidentally, the pipe capacity (portion of the heat exchange element 1) of Comparative Example 1 was the same as the main body capacity

(33cc) of the segments of heat exchange elements 1 of Examples 1 to 3. Comparative Example 1 had pipes having a dual structure where the second fluid flow passage is present in the outer peripheral portion of the pipe functioning as the first fluid flow passage. That is, it had a structure where the second fluid flows outside the pipe for the first fluid. It had a structure where the (cooling) water flows outside (gap of 5 mm) the pipe. The pipe capacity of Comparative Example 1 means capacity of the pipe functioning as the first fluid flow passage.

(Test result)

**[0084]** Table 1 shows heat exchange rate. The heat exchange rate (%) was obtained by calculating each energy amount from the  $\Delta T^{\circ}\text{C}$  (outlet temperature of heat exchange element - inlet temperature) of each of the first fluid (nitrogen gas) and the second fluid (water) with the formula 1.

(formula 1)      Heat exchange rate (%) = temperature rise  
energy amount of medium to be heated (second fluid) /  
temperature fall energy amount of heated medium (first  
fluid)

**[0085]**

[Table 1]

|             | Heat exchange element                               |         |                                                              |                                  |                                | Partition wall density (g/cm <sup>3</sup> ) | Partition wall thermal conductivity (W/mK) | Heat exchange efficiency (%) |
|-------------|-----------------------------------------------------|---------|--------------------------------------------------------------|----------------------------------|--------------------------------|---------------------------------------------|--------------------------------------------|------------------------------|
|             | Material                                            | Shape   | First fluid circulation portion (number of partition walls)  | Second fluid circulation portion | Route                          |                                             |                                            |                              |
| Example 1   | Silicon carbide                                     | Segment | Honeycomb structure, (6 partition walls)                     | Slit structure                   | Cross flow structure           | 0.5                                         | 10                                         | 85                           |
| Example 2   | Silicon carbide                                     | Segment | Honeycomb structure, (6 partition structure partition walls) | Slit structure                   | Cross flow structure           | 1.5                                         | 23                                         | 88                           |
| Example 3   | Silicon carbide                                     | Segment | Honeycomb structure (2 partition structure)                  | Slit structure                   | Cross flow structure           | 1.5                                         | 23                                         | 84                           |
| Example 4   | Silicon carbide (densification by SiC impregnation) | Segment | Honeycomb structure (6 partition walls)                      | Slit structure                   | Cross flow structure           | 3.0                                         | 150                                        | 92                           |
| Example 5   | Silicon carbide (densification by SiC impregnation) | Segment | Honeycomb structure (6 partition walls)                      | Slit structure                   | Cross flow structure           | 5.0                                         | 300                                        | 96                           |
| Comp. Ex. 1 | SUS304                                              |         | Piping structure                                             | Outside of structure             | Outer periphery flow structure | 7.5                                         | 15                                         | 79                           |
| Comp. Ex. 2 | Silicon carbide                                     | Segment | Honeycomb structure (6 partition walls)                      | Slit structure                   | Cross flow structure           | 0.3                                         | 8                                          | Broken during test           |

| (continued) |                                                     |         |                                                             |                                  |                      |                                             |                                            |                              |
|-------------|-----------------------------------------------------|---------|-------------------------------------------------------------|----------------------------------|----------------------|---------------------------------------------|--------------------------------------------|------------------------------|
|             | Heat exchange element                               |         |                                                             |                                  |                      | Partition wall density (g/cm <sup>3</sup> ) | Partition wall thermal conductivity (W/mK) | Heat exchange efficiency (%) |
|             | Material                                            | Shape   | First fluid circulation portion (number of partition walls) | Second fluid circulation portion | Route                |                                             |                                            |                              |
| Comp. Ex. 3 | Silicon cargide (densificationby) SiC impregnation) | Segment | Honeycomb structure (6 partition walls)                     | Slit structure                   | Cross flow structure | 5.1                                         | 320                                        | Broken during production     |

(Comparison of Examples 1 to 3 with Comparative Example 1)

**[0086]** As shown in Table 1, Example 1 showed high heat exchange efficiency in comparison with Comparative Example 1. This seems to be because, in the case of Comparative Example 1, though heat exchange with the first fluid (nitrogen gas) was easy on the side close to (cooling) water, sufficient heat exchange was hard in the central portion of the pipe, and thereby the thermal exchange rate was low as a whole. On the other hand, since the present invention has a honeycomb structure, the wall area where the first fluid (nitrogen gas) is brought into contact with (cooling) water is large in comparison with Comparative Example 1, and this seems to be the cause of high heat exchange efficiency.

(Comparison of Example 2 with Example 3)

**[0087]** As shown in Table 1, Example 2 had high heat exchange efficiency in comparison with Example 3. This shows that a honeycomb structure having more partition walls (Example 2) is more excellent in heat exchange than a honeycomb structure having less partition walls, and this seems to be because the wall area where the first fluid is brought into contact increases by a honeycomb structure having more partition walls.

(Comparison of Examples 1 to 3 with Examples 4 and 5)

**[0088]** As shown in Table 1, Examples 4 and 5 had high heat exchange efficiency in comparison with Examples 1 to 3. This seems to be because Examples 4 and 5 became dense bodies by impregnation of the segment of the heat exchange element 1 with Si to raise thermal conductivity. This shows that performing Si impregnation is more preferable.

(Comparison of Example 1 with Comparative Example 2)

**[0089]** As shown in Table 1, Example 1 had no breakage of partition walls during the test evaluation in comparison with Comparative Example 2. This seems to be because, since Comparative Example 2 had small partition wall density, strength was insufficient, and partition walls had a breakage during the test by the internal pressure of the fluid. From this, the partition wall density is more preferably 0.5 g/cm<sup>3</sup> or more.

(Comparison of Example 5 with Comparative Example 3)

**[0090]** As shown in Table 1, Example 5 had no breakage of the main body during the production of the heat exchange element 1 in comparison with Comparative Example 3. This seems to be because, though Comparison Example 3 had high strength due to high partition wall density, it was prone to break inversely, and thereby breakage was caused during the production of the heat exchange element 1. From this, in consideration of production of the heat exchange element 1, the partition wall density is more preferably 5 g/cm<sup>3</sup> or less.

#### Industrial Applicability

**[0091]** The use of heat exchange element of the present invention is not particularly limited in either the automobile field or the industrial field as long as heat exchange is performed between a heated medium (high temperature side) and a medium to be heated (low temperature side). In the case of using the heat exchange element for exhaust heat recovery from exhaust gas in the automobile field, it can be used to improve gas mileage of automobiles.

[Description of Reference Numerals]

**[0092]** 1: heat exchange element, 2: end face (in the axial direction), 3: cells, 4: partition wall, 5: first fluid circulation portion, 6: second fluid circulation portion, 7: outer peripheral wall, 8: bonding material layer, 10: heat exchanger, 11: heat exchange element-holding container, 12: end face, 13: plugged portion, 14: inter-slit partition wall, 19: fluid sealing material

#### Claims

1. A ceramics heat exchanger comprising:

first fluid circulation portions having a honeycomb structure having a plurality of cells separated by ceramic partition walls, extending through in an axial direction from one end face to the other end face, and allowing a

heated medium as a first fluid to flow therethrough, and  
 second fluid circulation portions being separated by ceramic partition walls, extending in the direction perpen-  
 dicular to the axial direction, being isolated from the first fluid circulation portions by the partition walls to be  
 capable of heat conduction, allowing a second fluid to flow therethrough, receiving the heat of the first fluid  
 circulating in the first fluid circulation portions by means of the partition walls, and having cells for transferring  
 heat to a medium to be heated as the second fluid;

wherein the first fluid circulation portions and the second fluid circulation portions are alternately formed as a  
 unit, the cells on the first fluid circulation portion side are smaller than the cells on the second fluid circulation  
 portion side, and the partition walls have a density of 0.5 to 5 g/cm<sup>3</sup> and a thermal conductivity of 10 to 300 W/mK.

2. The ceramics heat exchanger according to Claim 1, wherein each of the second fluid circulation portions has a slit  
 structure having no separating partition wall or having 1 to 50 separating partition walls.

3. The ceramics heat exchanger according to Claim 1 or 2, wherein a plurality of the heat exchange elements are  
 bonded together by means of a bonding material layer of heat resistant cement.

4. The ceramics heat exchanger according to any one of Claims 1 to 3, wherein SiC is contained in the ceramics  
 constituting the partition walls.

5. The ceramics heat exchanger according to any one of Claims 1 to 4, wherein the ceramics constituting the partition  
 walls is Si-impregnated SiC.

6. The ceramic heat exchanger according to any one of Claims 1 to 5, wherein the first fluid is gas, and the second  
 fluid is liquid.

7. The ceramic heat exchanger according to any one of Claims 1 to 6, wherein a catalyst is loaded on wall surfaces  
 of the first fluid circulation portions.

8. A method for manufacturing a ceramics heat exchanger comprising the steps of:

forming a honeycomb structure having a plurality of cells separated by ceramic partition walls and extending  
 through in an axial direction from one end face to the other end face by extruding a ceramic forming raw material,  
 forming slits with regard to a part of a plurality of cell lines to extend through the partition walls forming the cells  
 and the outer peripheral wall of the honeycomb structure in the direction perpendicular to the axial direction, and  
 forming plugged portions plugged with a plugging member on one end face and the other end face of the cells  
 in the cell lines where slits are formed.

FIG.1

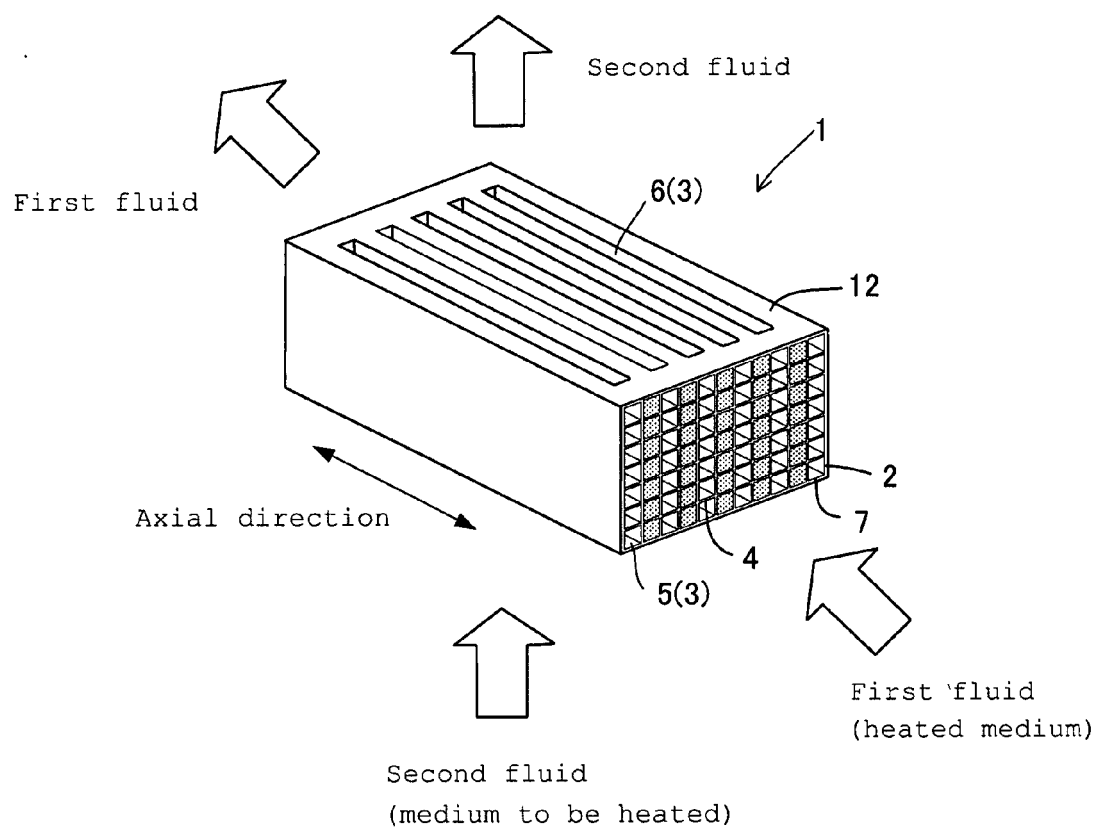


FIG.2A

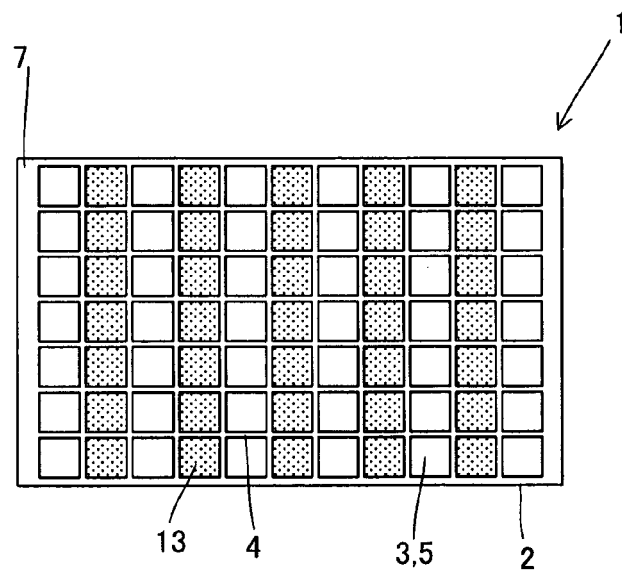


FIG.2B

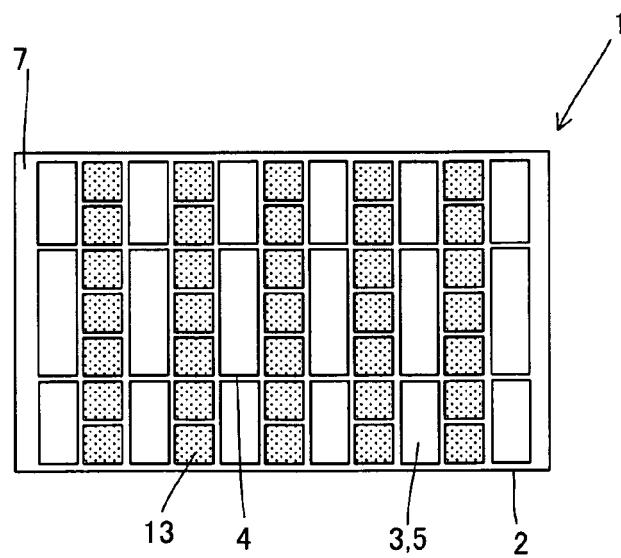


FIG.3A

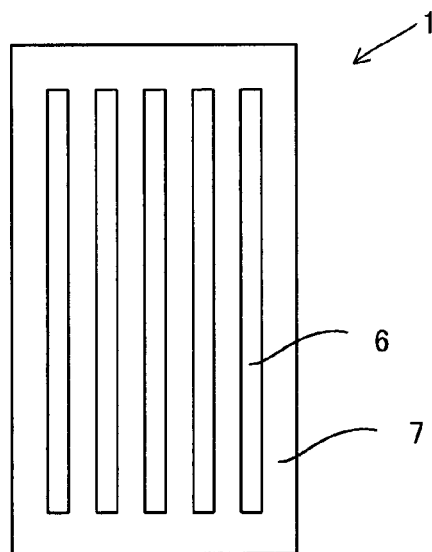


FIG.3B

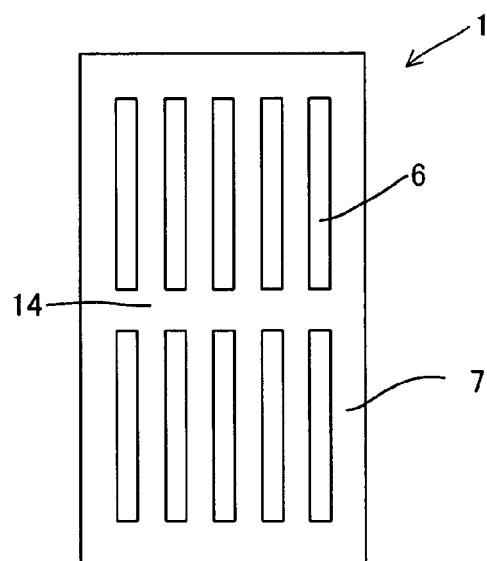


FIG.4

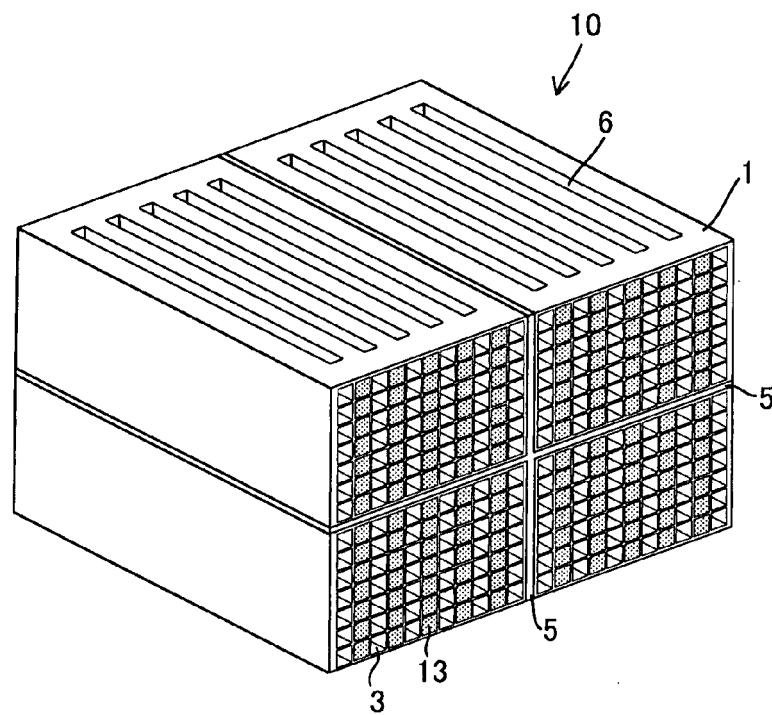


FIG.5

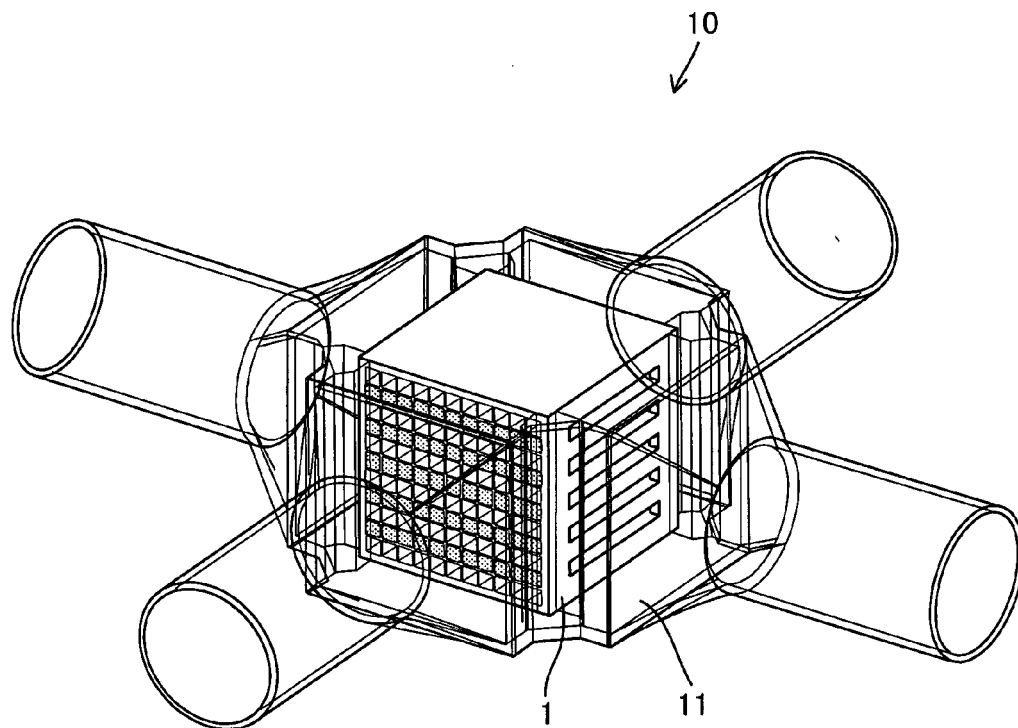


FIG.6

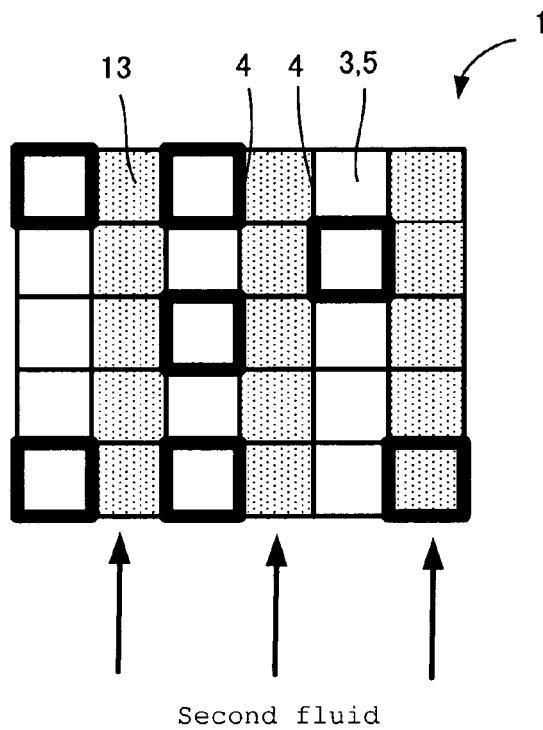


FIG.7A

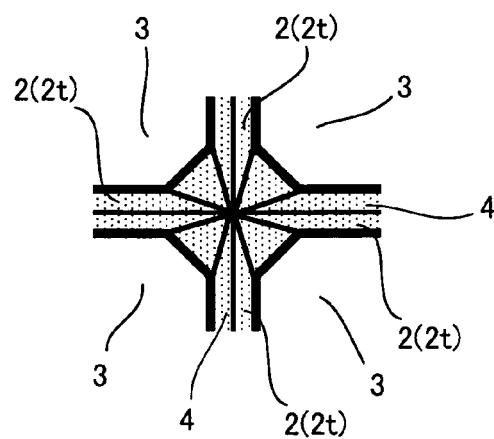


FIG.7B

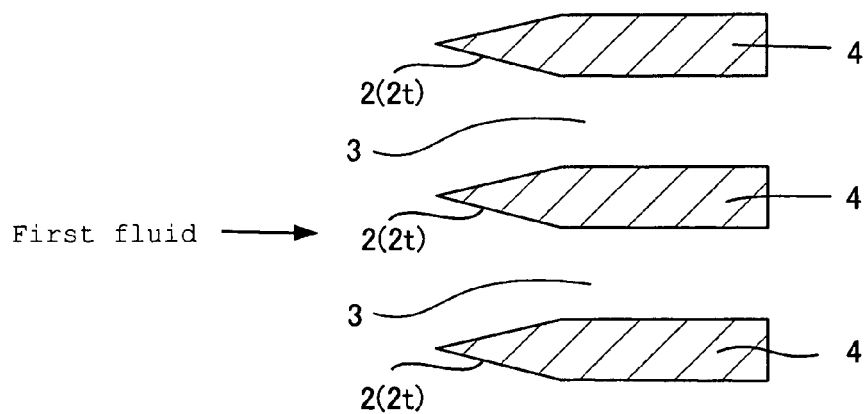


FIG.8A

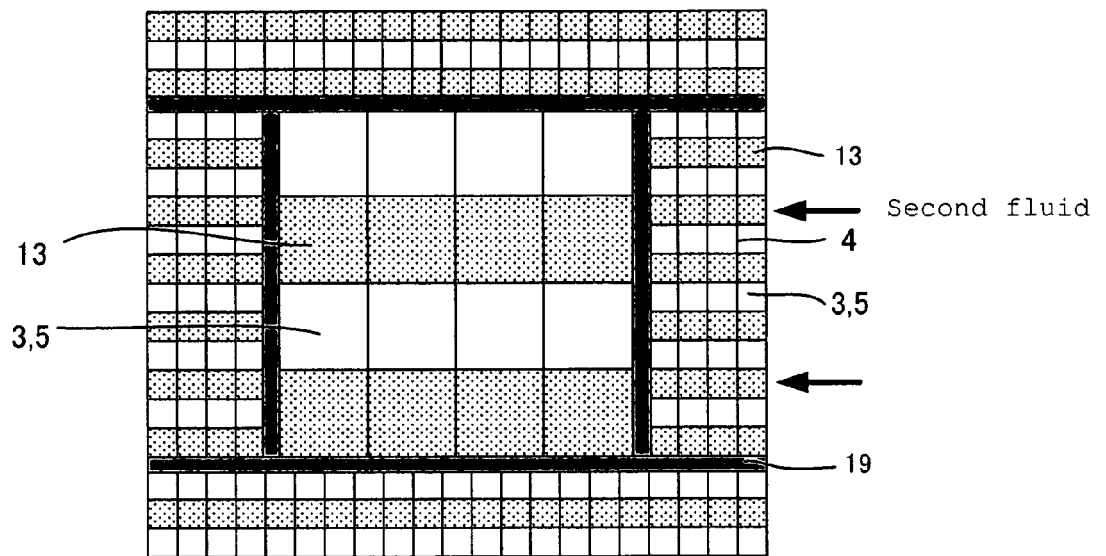


FIG.8B

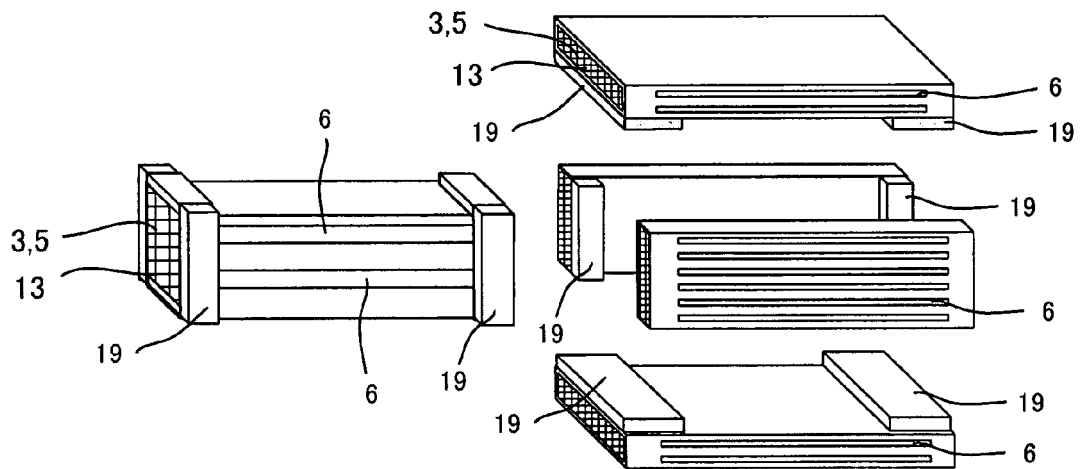


FIG.8C

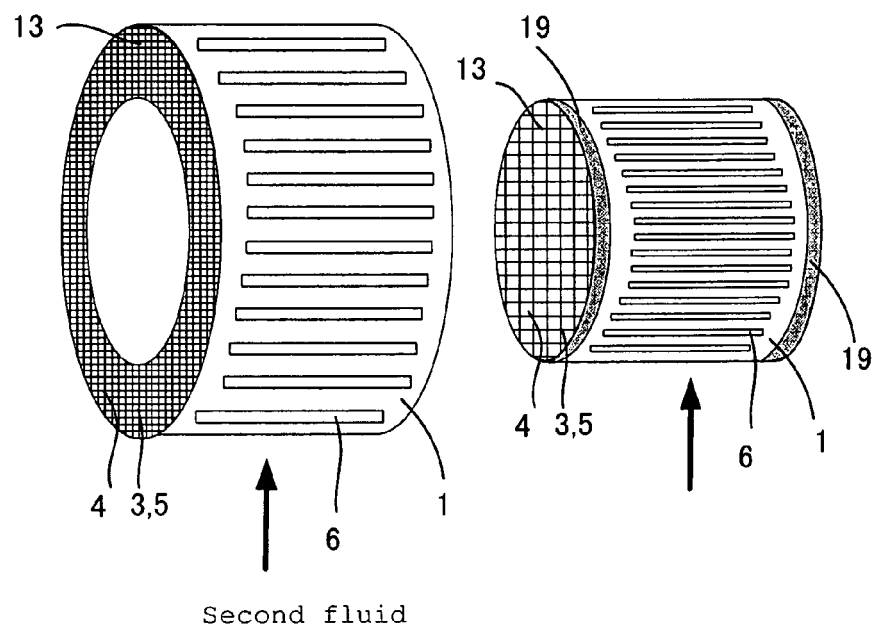


FIG.8D

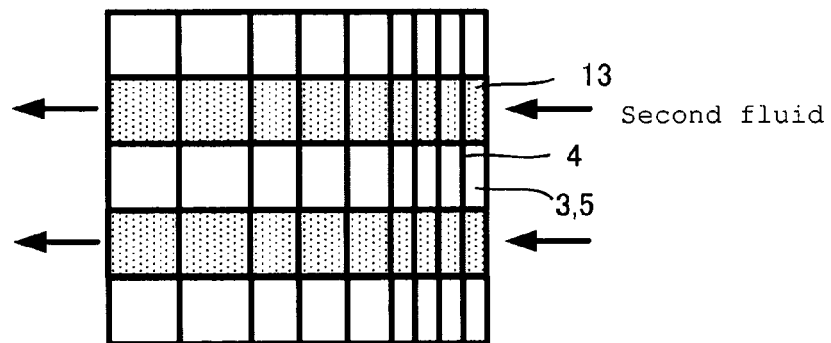


FIG.8E

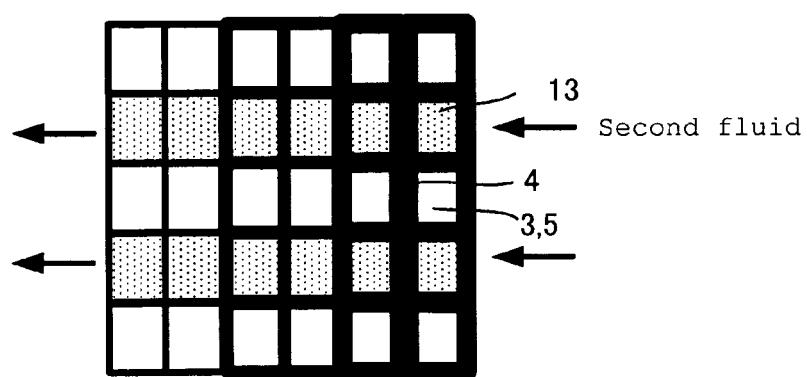


FIG.9A

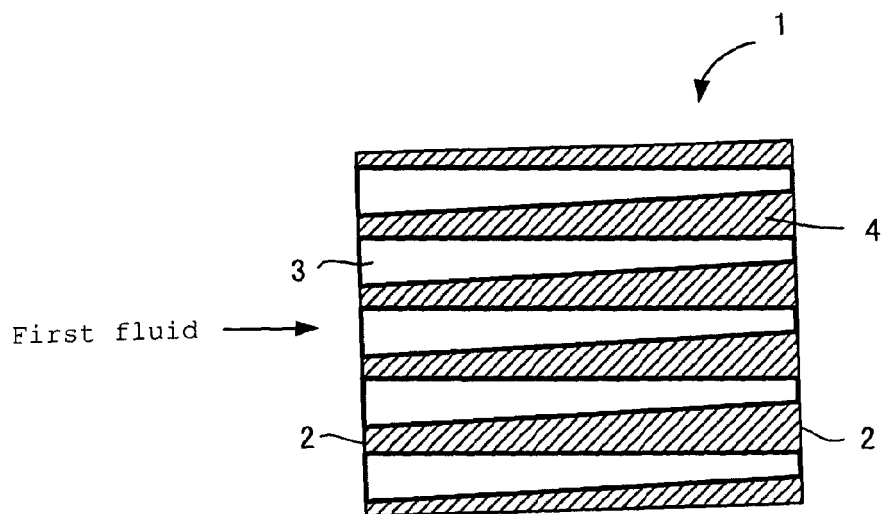


FIG.9B

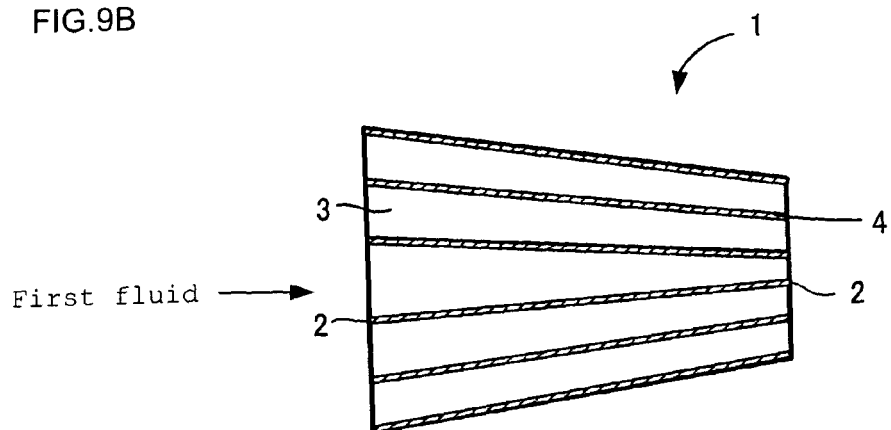


FIG.10A

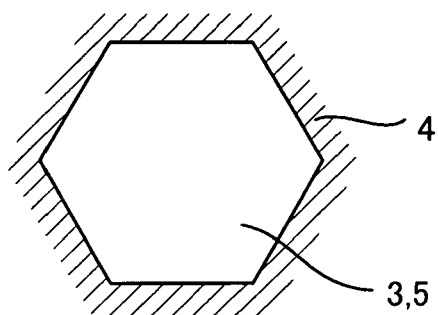


FIG.10B

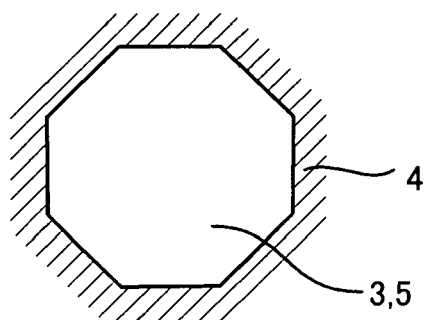


FIG.11

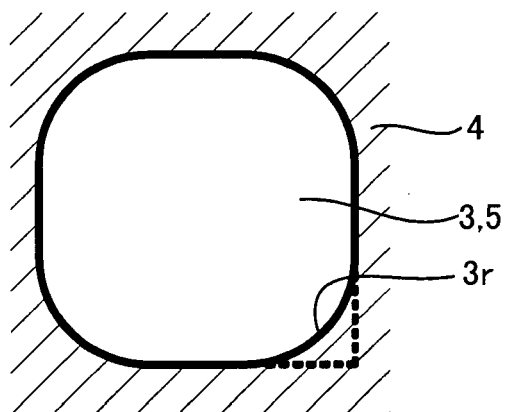


FIG.12A

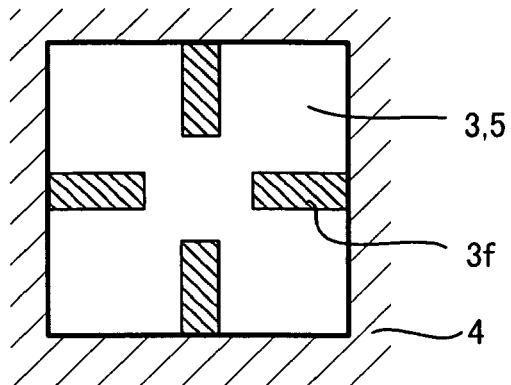


FIG.12B

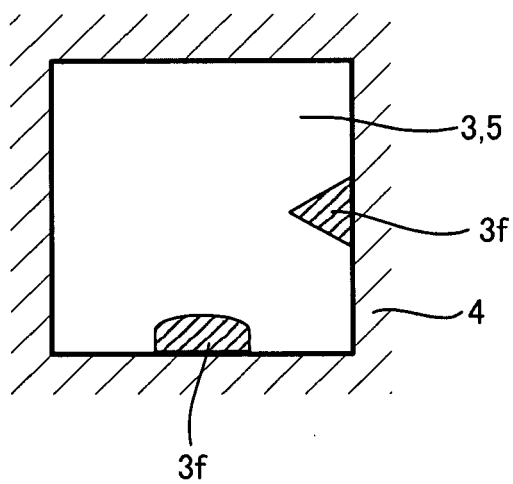


FIG.13A

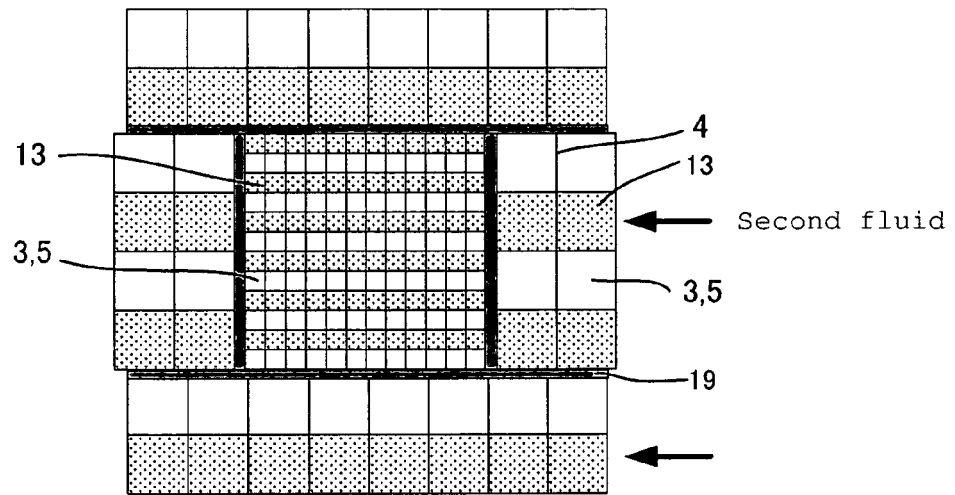


FIG.13B

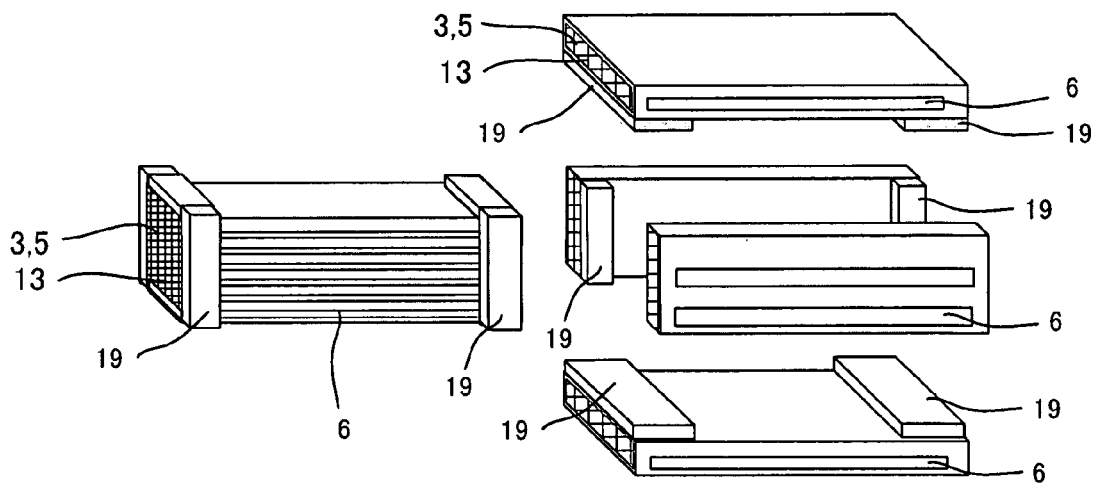


FIG.13C

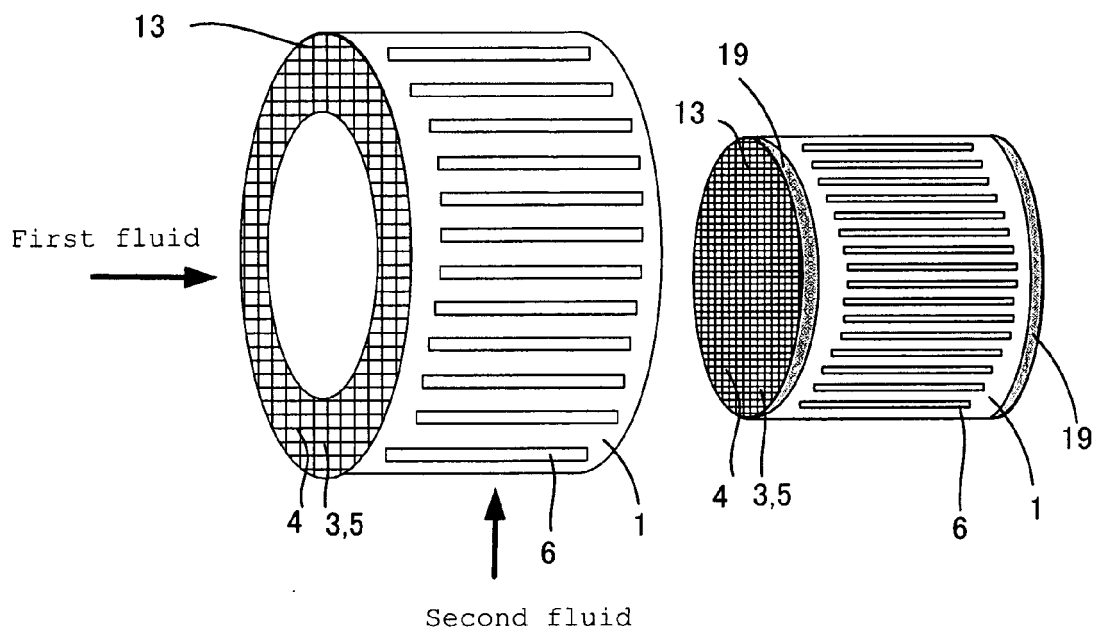


FIG.13D

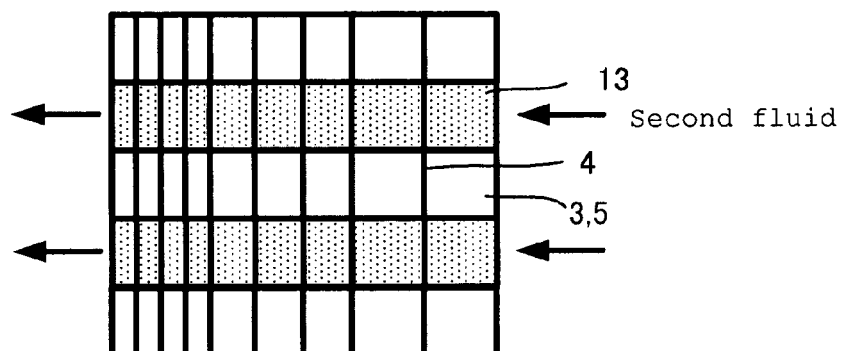


FIG.13E

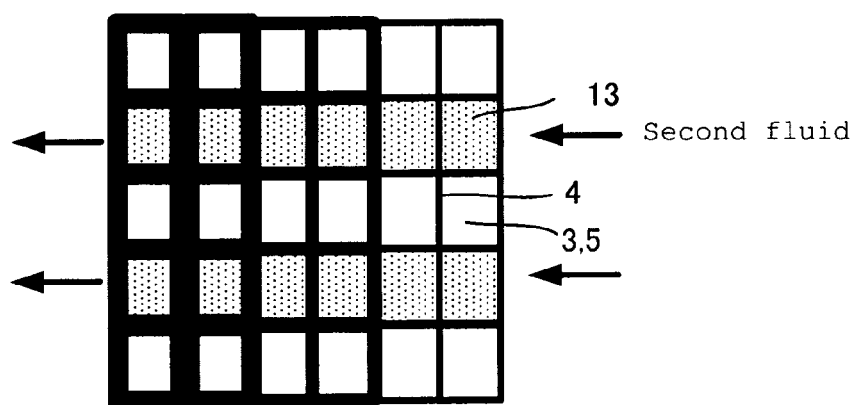


FIG.14A

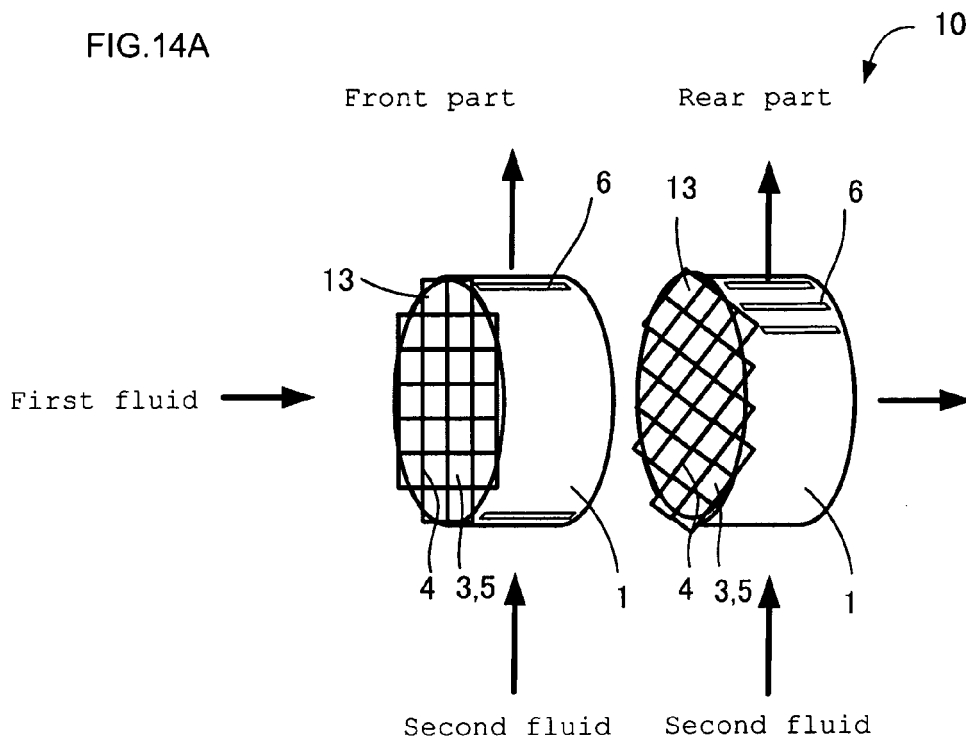


FIG.14B

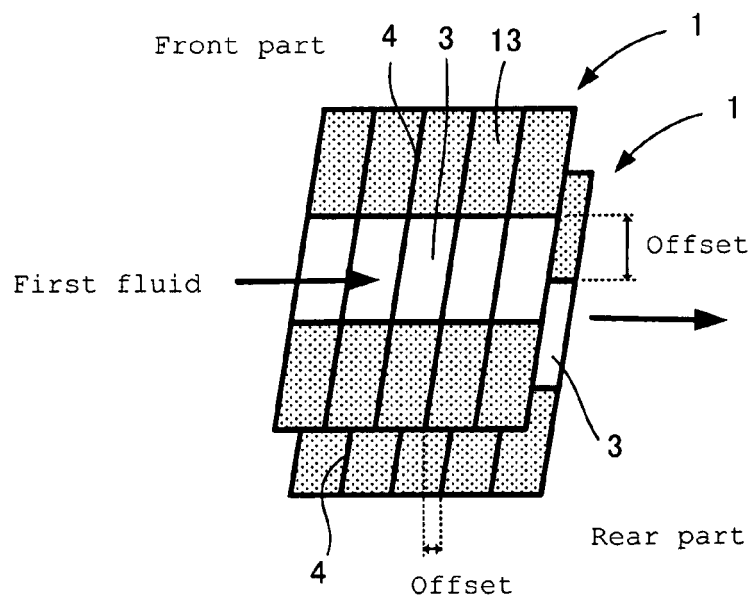


FIG.15

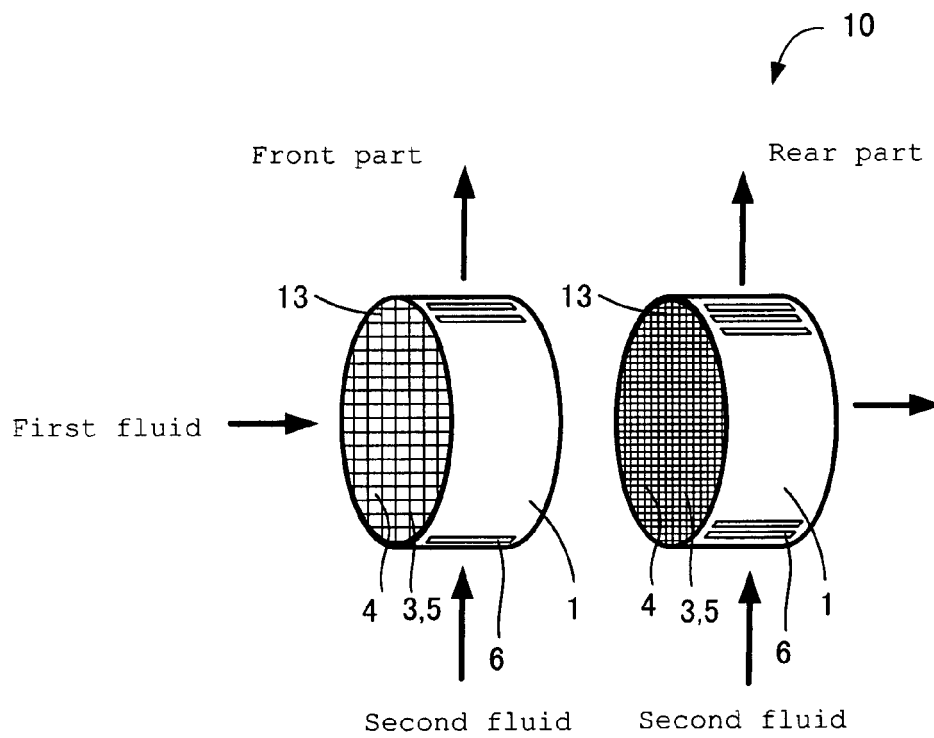


FIG.16

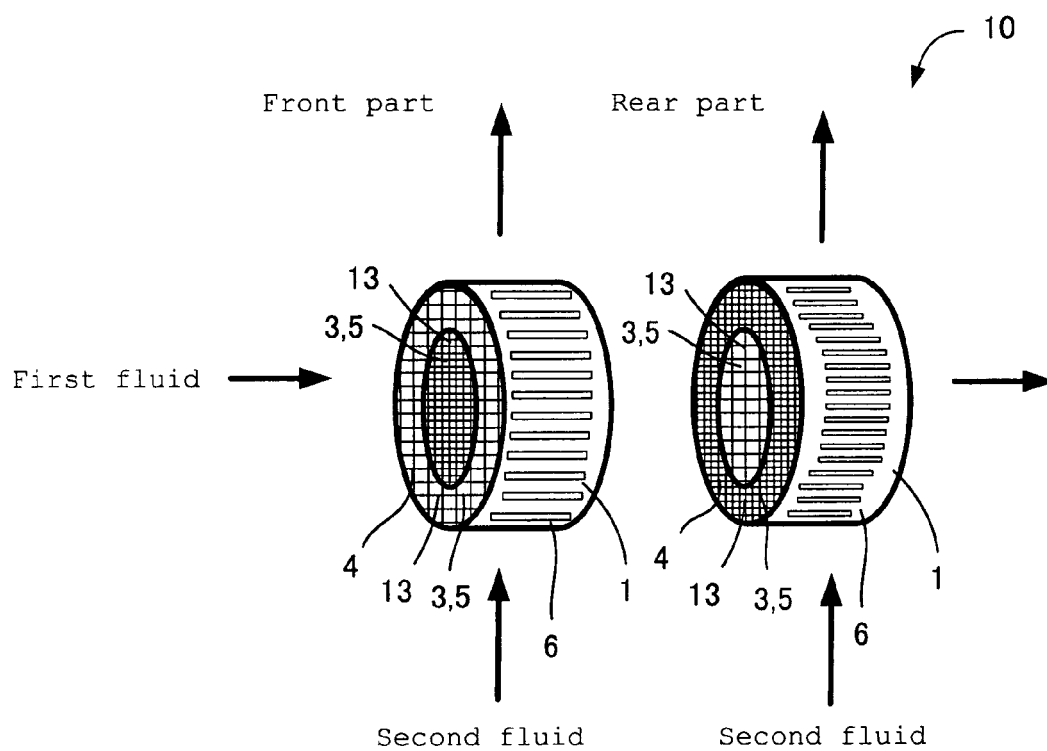


FIG.17A

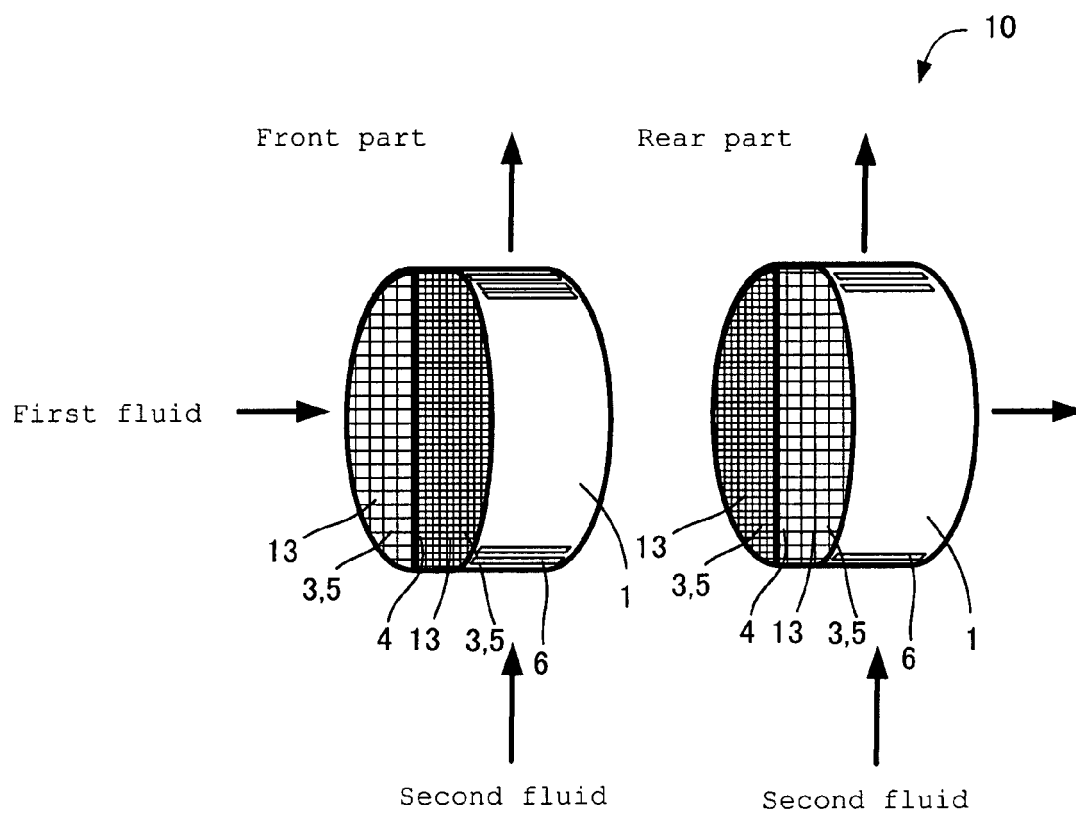


FIG.17B

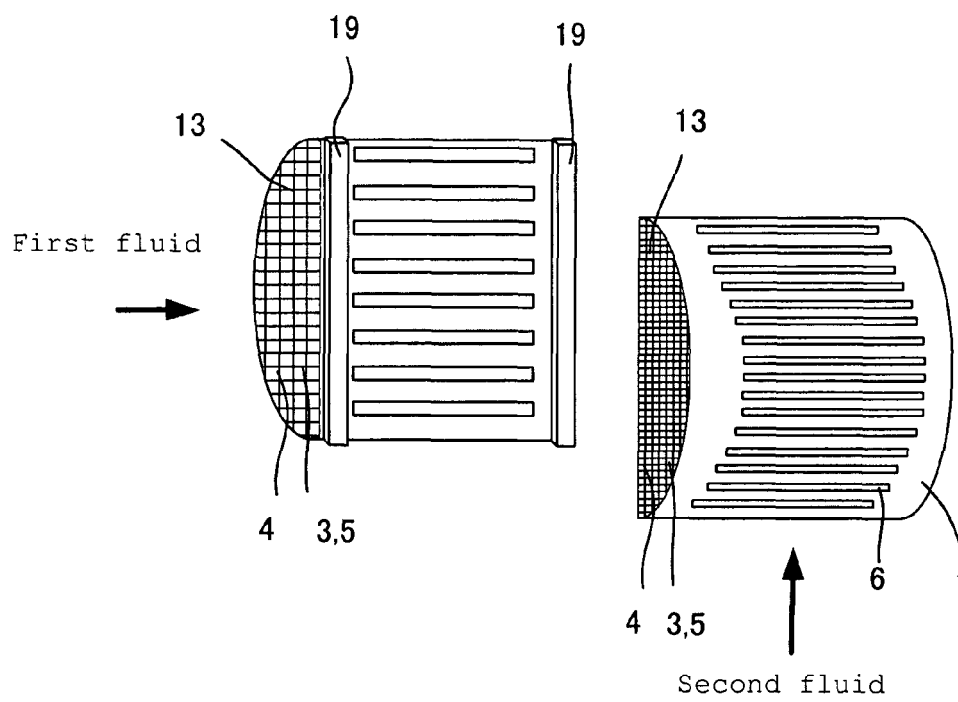


FIG.17C

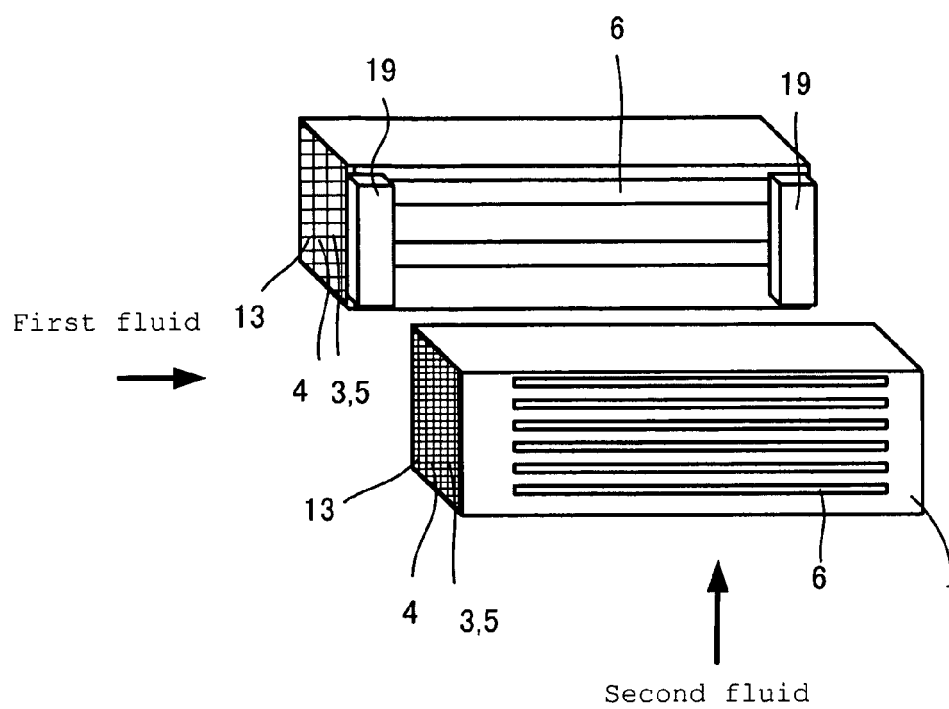


FIG.18A

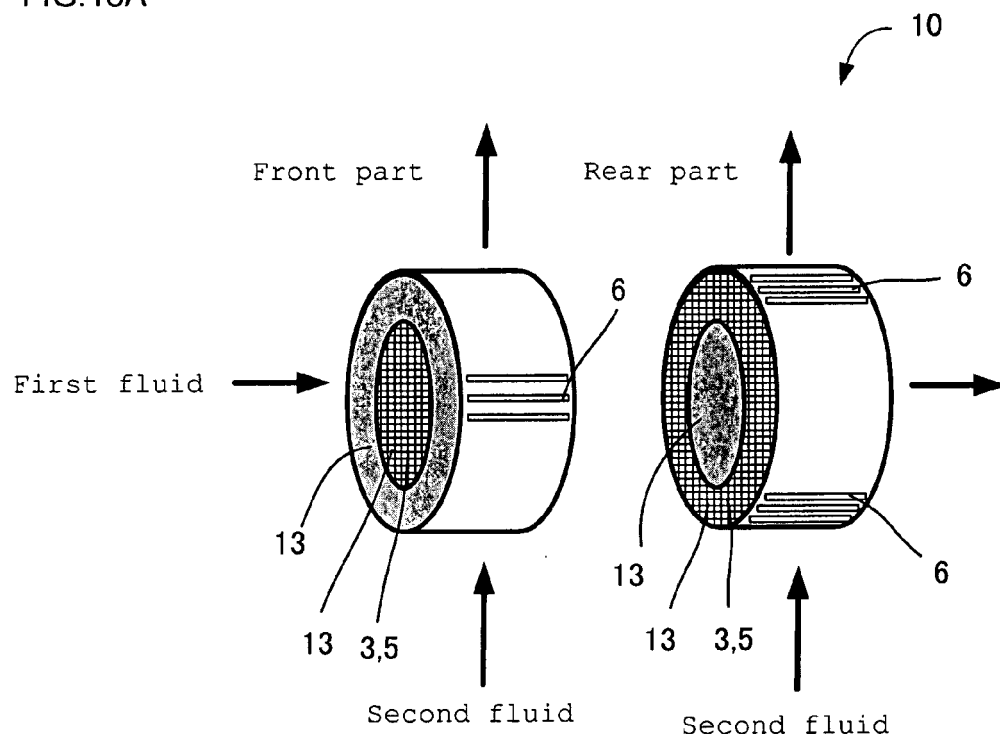


FIG.18B

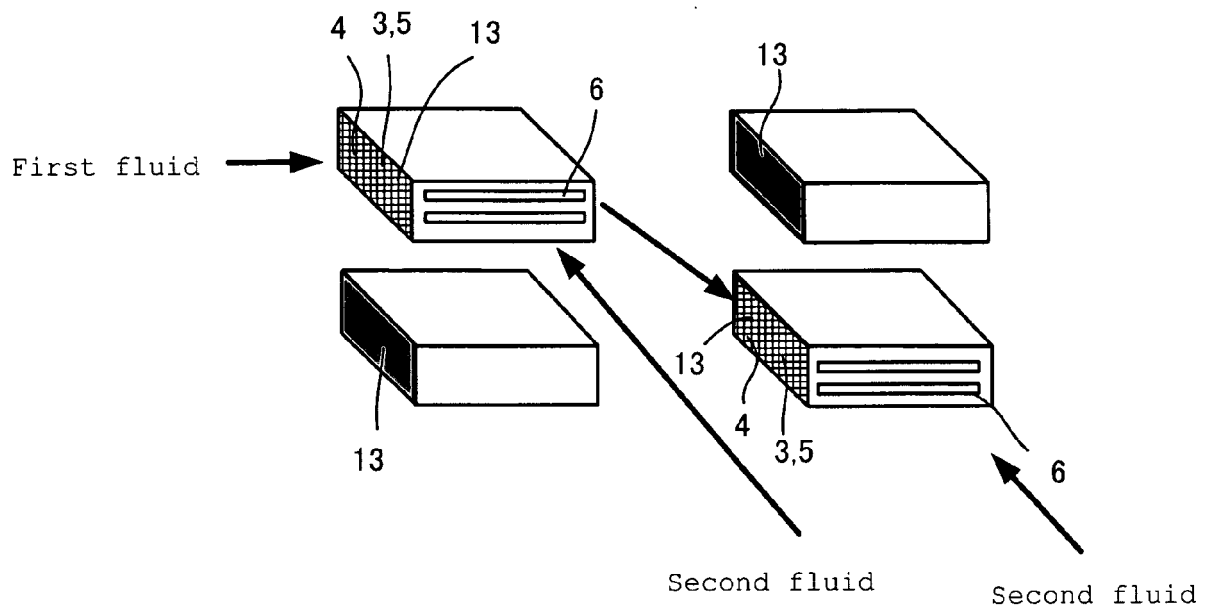


FIG.19A

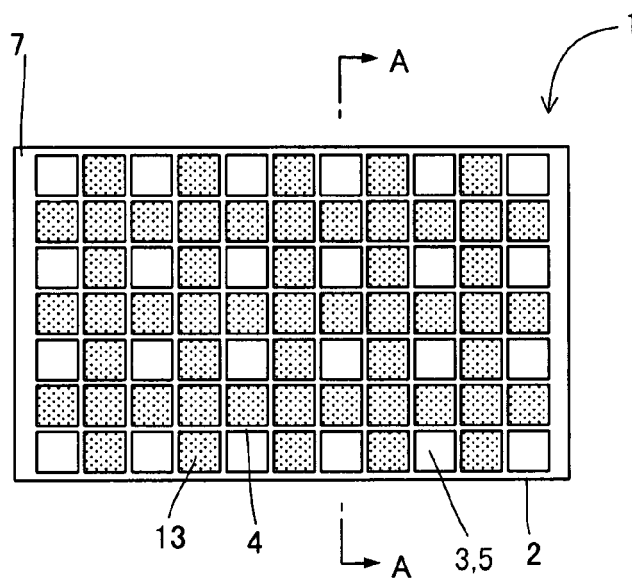


FIG.19B

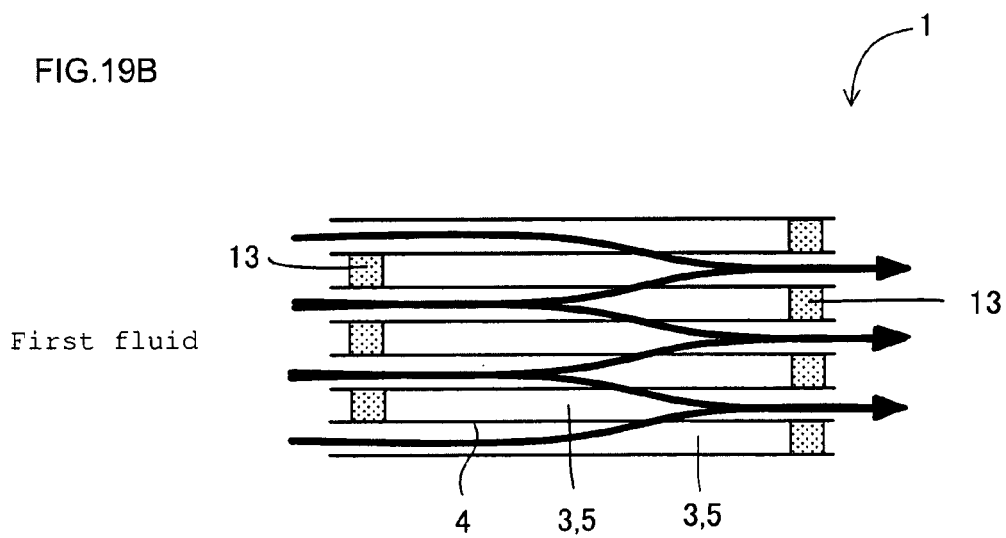


FIG.20

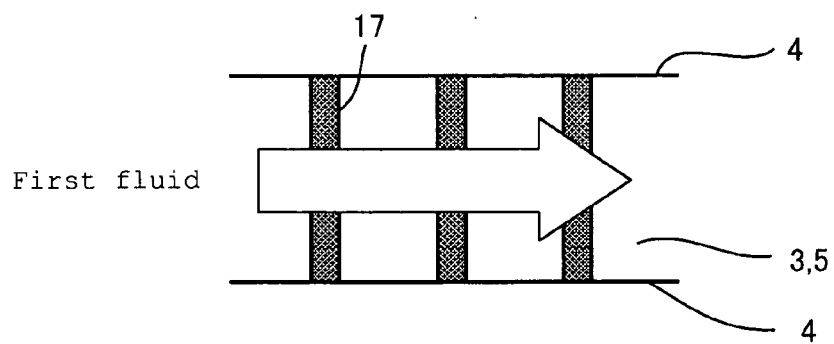


FIG.21

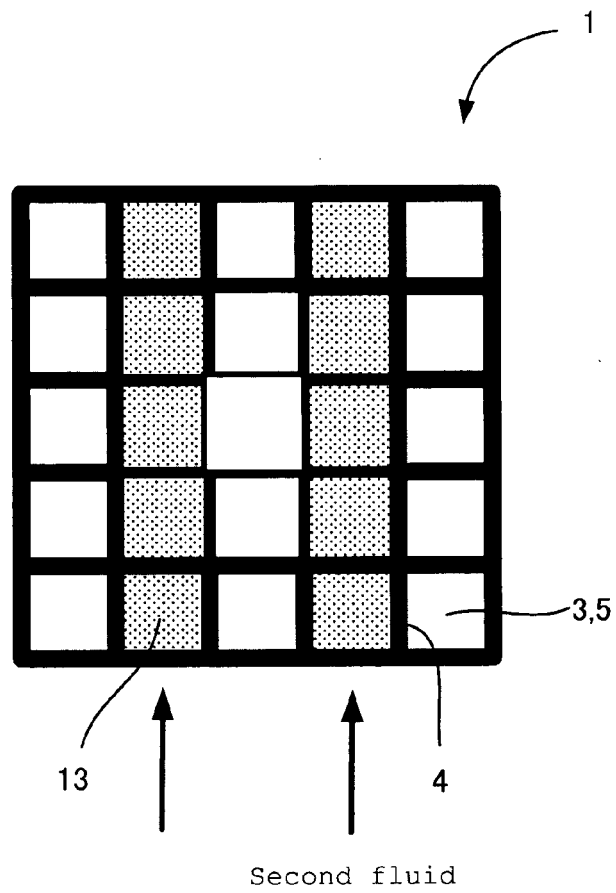


FIG.22

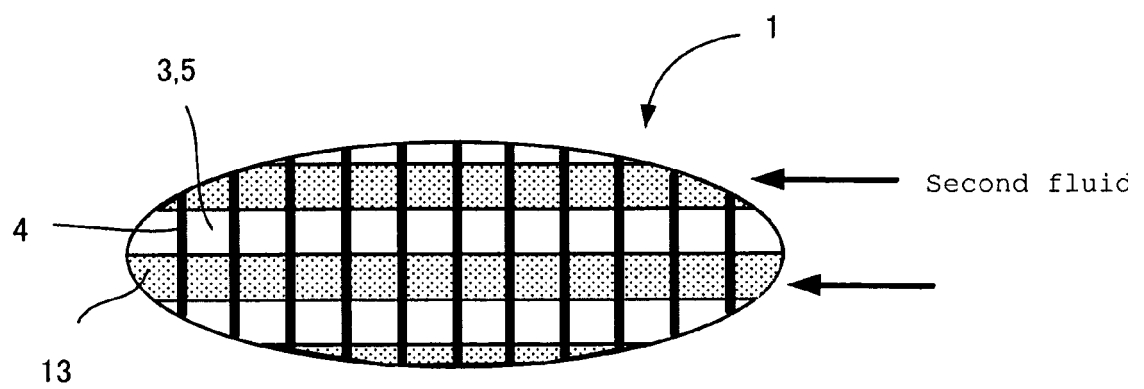


FIG.23

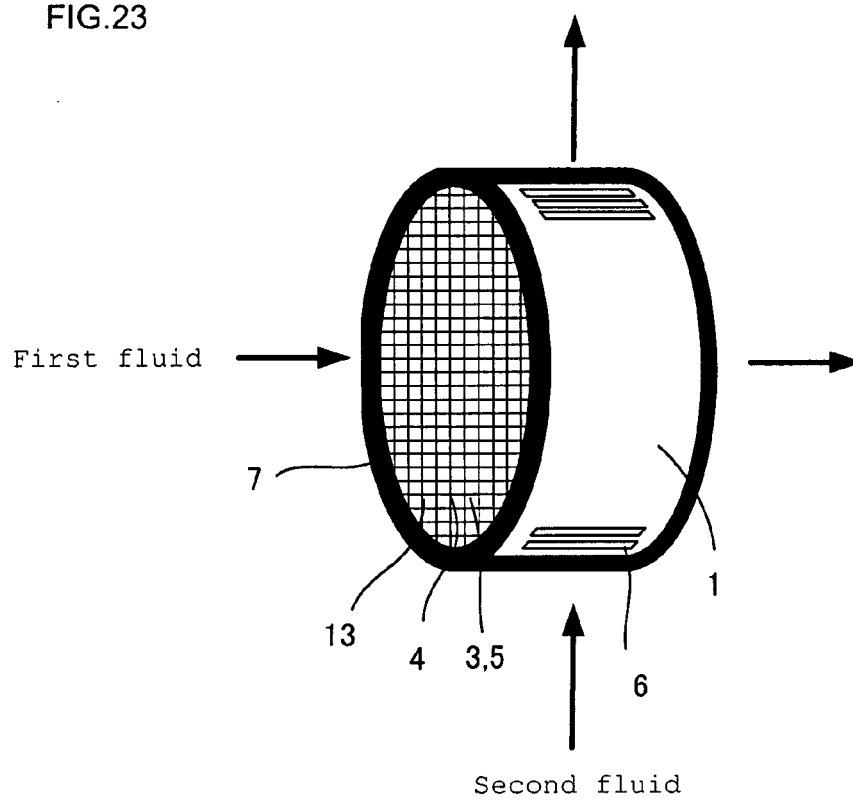


FIG.24

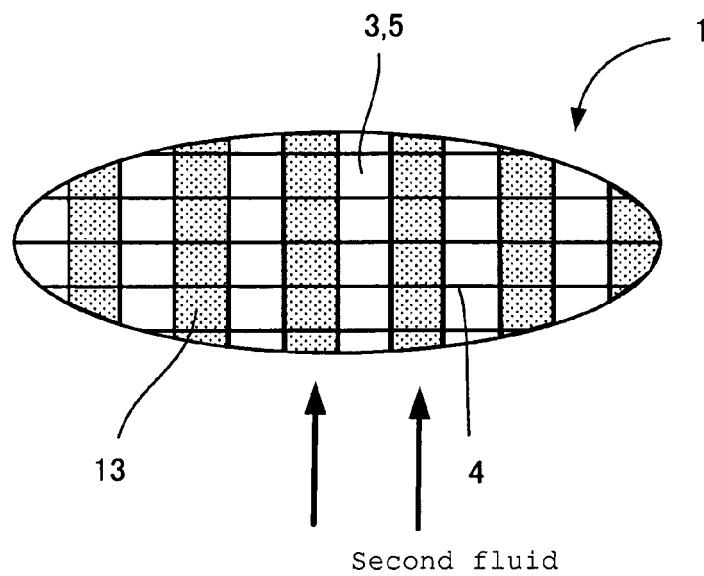


FIG.25A

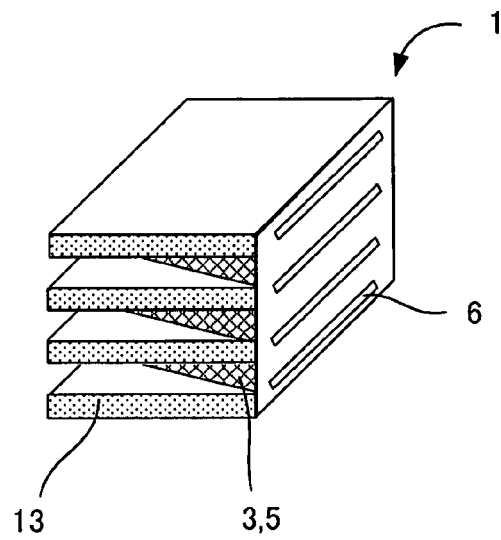


FIG.25B

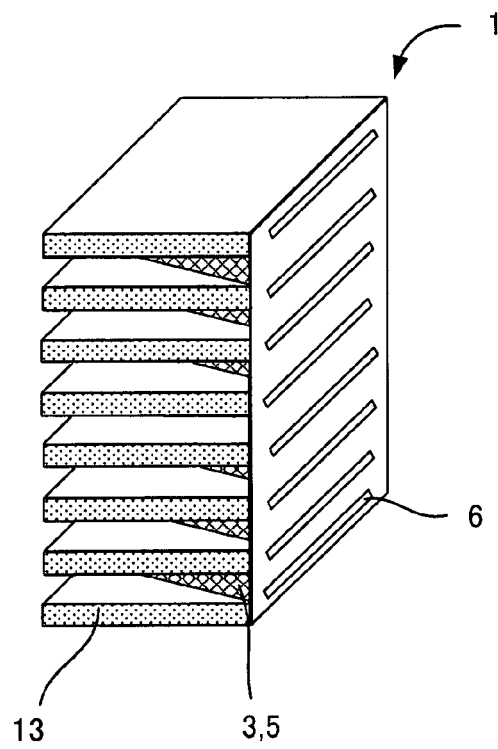


FIG.25C

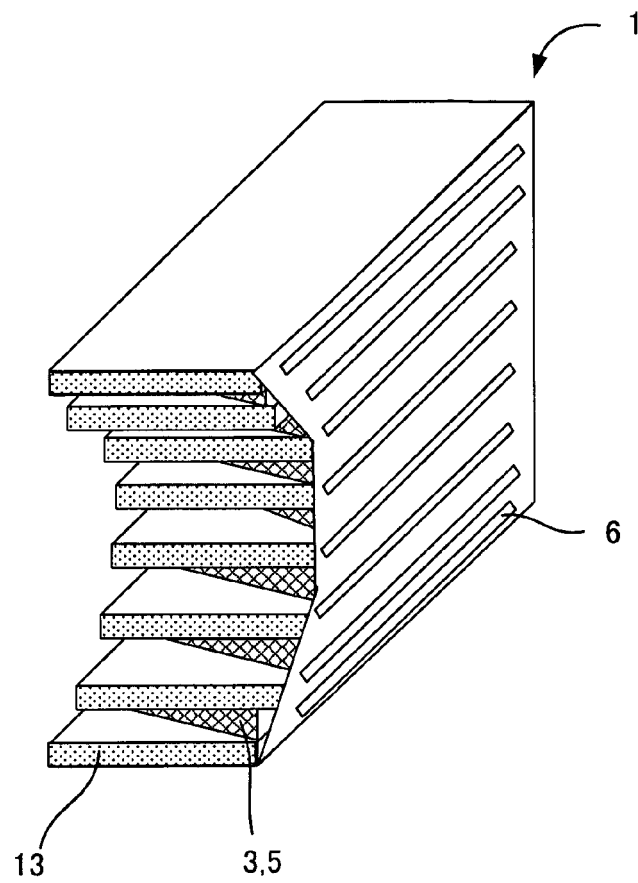


FIG.26

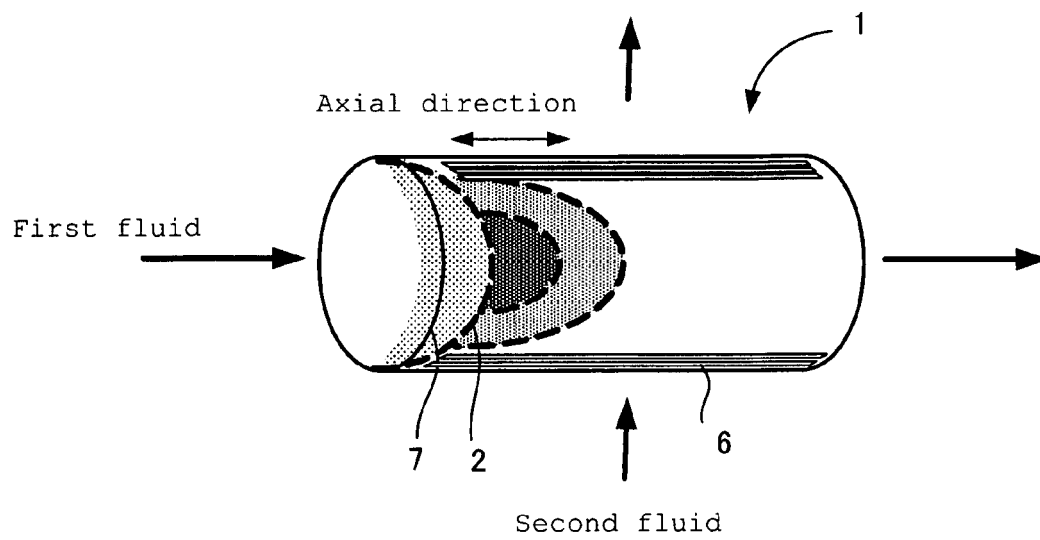
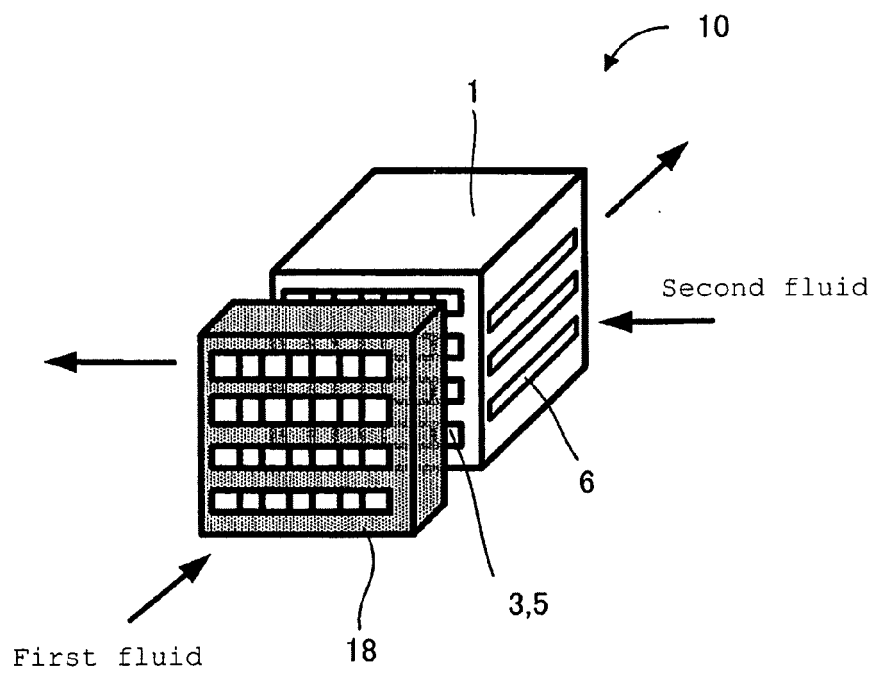


FIG.27



**REFERENCES CITED IN THE DESCRIPTION**

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