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(54) **POROUS ALUMINUM OBJECT, HEAT TRANSFER MATERIAL, AND HEAT EXCHANGER**

(57) Provided is a porous aluminum body capable of being used as a heat transfer material having a very large specific surface area, a good heat-exchange efficiency, and a low pressure drop of a gas. The porous aluminum body contains aluminum as a main component. The porous aluminum body has a three-dimensional network structure and has a specific surface area (Y) represented by a (Formula) below.

$$Y = a \times \exp(0.06X) \quad (\text{Formula})$$

(In the (Formula), Y represents a specific surface area [m²/m³], X represents the number of cells [per inch], and a represents a number of 100 or more and 1,000 or less.)

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Description

Technical Field

5 **[0001]** The present invention relates to a porous aluminum body having a three-dimensional network structure, a heat transfer material, and a heat exchange device.

Background Art

10 **[0002]** Metallic materials having high thermal conductivities are used as heat transfer materials used in heat exchange devices and the like. Furthermore, for the purpose of reducing the size of the devices by increasing the heat-exchange efficiency, an increase in the surface area of a heat transfer material has been studied. For example, the surface area of a heat transfer material is increased by arranging a large number of thin plates composed of a heat transfer material or by forming grooves in a heat transfer material.

15 **[0003]** For example, Japanese Unexamined Patent Application Publication No. 07-190664 (PTL 1) has proposed the use of a porous copper body or a porous copper alloy body as a heat transfer member. Specifically, this technique uses a property that a copper oxide powder or a mixed powder of a copper oxide powder and a powder of another metal such as nickel, aluminum, chromium, palladium, or silver is sintered as a metal in a reducing atmosphere and a property that when this sintering is performed on a metal plate, the resulting sintered product can be integrated with the metal plate.

20 PTL 1 describes that this technique can provide a heat transfer tube or a heat transfer plate in which a porous metal body having a three-dimensional network structure is integrally adhered to an inner or outer surface of a metal tube or a surface of a metal plate.

25 **[0004]** Electronic components etc. that use semiconductor circuits generate heat during use, and thus efficient heat dissipation has been desired. For example, Japanese Unexamined Patent Application Publication No. 2012-124391 (PTL 2) has proposed a heat transfer controlling member that controls heat transfer between a heating element and a peripheral environment thereof, the heat transfer controlling member including a porous metal layer having a three-dimensional network structure.

30 **[0005]** In the heat transfer controlling member described in PTL 2, the porous metal layer is composed of a foamed metal having a three-dimensional network structure in which a plurality of pores formed by a continuous skeleton are communicated with each other, and has a porosity of 30% to 98% and a thickness of 0.05 to 50 mm. This foamed metal is formed by forming a foamable slurry containing a metal powder, a foaming agent, etc. into a sheet, and foaming the resulting sheet. Pores in the foamed metal are opened on a front surface, a back surface, and side surfaces. The foamed metal is formed so as to be dense in the vicinity of the front and back surfaces relative to a central portion in the thickness direction. In addition, one of the front surface and the back surface is formed so as to be denser than the other surface.

35 **[0006]** In a heat transfer material including such a porous metal body prepared by the sintering method described above, in order to increase the heat-exchange efficiency in a certain volume, it is necessary to decrease the cell diameter of the porous metal body so as to increase the specific surface area. However, when the cell diameter is decreased in order to increase the heat-exchange efficiency, there may be a problem in that a pressure drop of a gas which passes through the porous metal body increases.

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Citation List

Patent Literature

45 **[0007]**

PTL 1: Japanese Unexamined Patent Application Publication No. 07-190664

PTL 2: Japanese Unexamined Patent Application Publication No. 2012-124391

50 Summary of Invention

Technical Problem

55 **[0008]** In view of the above problem, an object of the present invention is to provide a porous aluminum body capable of being used as a heat transfer material having a very large specific surface area, a good heat-exchange efficiency, and a low pressure drop of a gas.

Solution to Problem

[0009] The inventors of the present invention have conducted intensive studies in order to solve the above problem. As a result, it was found that the specific surface area of a porous aluminum body can be markedly increased by further improving an existing method for producing a porous aluminum body having a three-dimensional network structure by a plating method (for example, Japanese Unexamined Patent Application Publication No. 2011-225950), and this finding led to the completion of the present invention. Specifically, the present invention has features described below.

[0010]

(1) A porous aluminum body containing aluminum as a main component, in which the porous aluminum body has a three-dimensional network structure and has a specific surface area (Y) represented by a (Formula) below.

$$Y = a \times \exp(0.06X) \quad (\text{Formula})$$

(In the (Formula), Y represents a specific surface area [m^2/m^3], X represents the number of cells [per inch], and a represents a number of 100 or more and 1,000 or less. The Napier's constant (e) is assumed to be 2.72.)

The porous aluminum body according to (1) above has very small irregularities over the entire surface of a skeleton thereof, and has a specific surface area that is significantly larger than that of an existing porous aluminum body. Furthermore, since aluminum is a metal having a high thermal conductivity, the porous aluminum body can be used as a heat transfer material having a good heat-exchange efficiency and a low pressure drop of a gas.

Note that, in the present invention, the phrase "containing aluminum as a main component" means that the aluminum content in the porous aluminum body is 90% by mass or more.

(2) The porous aluminum body according to (1) above, in which the porous aluminum body has a hollow skeleton. By producing the porous aluminum body by a plating method, the skeleton of the porous aluminum body can be made hollow. The porous aluminum body having such a hollow skeleton can allow a gas to flow even into the inside of the skeleton, and thus can be used as a heat transfer material having a higher heat-exchange efficiency.

(3) The porous aluminum body according to (1) or (2) above, in which aluminum contained in the porous aluminum body has a purity of 99.7% by mass or more.

As described above, aluminum is a metal having a high thermal conductivity. Accordingly, a porous aluminum body having a higher thermal conductivity can be obtained by increasing the purity of aluminum.

(4) The porous aluminum body according to any one of (1) to (3) above, in which a weight per volume of the porous aluminum body is 0.1 g/cm^3 or more and 1.0 g/cm^3 or less.

When the weight per volume of the porous aluminum body is 0.1 g/cm^3 or more, the thickness of the skeleton of the porous aluminum body can be made large and the specific surface area is increased. Consequently, the heat-exchange efficiency is improved.

In addition, since the cross-sectional area of the skeleton is increased, the thermal conductivity is improved. When the weight per volume of the porous aluminum body is 1.0 g/cm^3 or less, an increase in the pressure drop can be suppressed. Furthermore, an excessive increase in the production cost of the porous aluminum body can be suppressed.

Note that the term "weight per volume of a porous aluminum body" in the present invention refers to the mass per unit volume of the porous aluminum body.

(5) A heat transfer material including the porous aluminum body according to any one of (1) to (4) above.

The heat transfer material according to (5) above is a heat transfer material having a good performance, namely, a very large specific surface area, a good heat-exchange efficiency, and a low pressure drop of a gas.

(6) A heat exchange device using the porous aluminum body according to any one of (1) to (4) above.

[0011] In the heat exchange device according to (6) above, the porous aluminum body of the present invention is used as a heat transfer material. Thus, the heat exchange device has a very high heat-exchange efficiency. Therefore, the size of the heat exchange device can be reduced as compared with an existing heat exchange device.

Advantageous Effects of Invention

[0012] According to the present invention, it is possible to provide a porous aluminum body capable of being used as a heat transfer material having a very large specific surface area, a good heat-exchange efficiency, and a low pressure drop of a gas.

Brief Description of Drawings

[0013]

[Fig. 1] Figure 1 is a diagram illustrating an equivalent circuit for evaluating capacitance.

[Fig. 2] Figure 2 is a schematic view illustrating a measurement cell for measuring alternating current impedance.

Description of Embodiments

<Porous aluminum body>

[0014] A porous aluminum body according to the present invention contains aluminum as a main component. The porous aluminum body has a three-dimensional network structure and has a specific surface area (Y) represented by a (Formula) below:

$$Y = a \times \exp(0.06X) \quad (\text{Formula})$$

(In the (Formula), Y represents a specific surface area [m^2/m^3], X represents the number of cells [per inch], and a represents a number of 100 or more and 1,000 or less.)

[0015] As described above, the porous aluminum body according to the present invention has fine irregularities on the surface of a skeleton thereof, and has a very large specific surface area. That is, the specific surface area can be made larger than that of an existing porous aluminum body without decreasing the cell diameter more than necessary. Accordingly, by using the porous aluminum body of the present invention as a heat transfer material, the heat-exchange efficiency can be improved while the porous aluminum body has a certain degree of large cell diameter so that the pressure drop is maintained to be low.

[0016] In the (Formula), X represents the number of cells [per inch] of the porous aluminum body, and is preferably 6 to 60 per inch. When the number of cells of the porous aluminum body is 6 per inch or more, the specific surface area can be made sufficiently large and the heat-exchange efficiency can be made high. When the number of cells of the porous aluminum body is 60 per inch or less, an excessive increase in the pressure drop can be suppressed.

[0017] The number of cells of the porous aluminum body is more preferably 10 to 33 per inch, and still more preferably 10 to 20 per inch.

[0018] In the present invention, the number (X) of cells of the porous aluminum body is defined as the number of cells per 1 inch (25.4 mm). The number of cells can be determined as follows. A porous aluminum body is sliced in the horizontal direction, and observed with a microscope to obtain an enlarged image. A straight line having a length of 1 inch is drawn on the enlarged image, and the number of cells intersecting the straight line is counted. In this case, the number of cells is counted at five positions, and the average of the five positions is determined.

[0019] In the case where a resin body such as urethane foam is used as a starting material for producing a porous aluminum body, the number of cells of the porous aluminum body is the same as the number of cells of the resin body. The number of cells of the resin foam body can also be determined as in the case of the porous aluminum body.

[0020] In the (Formula), a represents a number of 100 or more and 1,000 or less. The number a is preferably 200 or more and 1,000 or less, and still more preferably 600 or more and 1,000 or less.

[0021] In the present invention, the term "specific surface area (Y)" refers to a value measured by a capacitance method. The capacitance method is a measurement method that uses a phenomenon that the capacitance of a metallic material is proportional to the surface area of the metallic material, as represented by a theoretical formula described below:

(Theoretical formula)

$$C = \varepsilon \times (A/d)$$

C: capacitance, ε : dielectric constant, d: distance between two electrodes, A: surface area of sample

[0022] Specifically, first, a plurality of aluminum plates having the same purity as a sample and having known surface areas are prepared. The capacitance of each of the aluminum plates is evaluated, and a calibration curve of "capacitance" versus "surface area" is prepared. The capacitance of the sample is then evaluated. Thus, the surface area of the sample can be determined by a calibration curve method.

[0023] The capacitance of each of the aluminum plates for preparing the calibration curve and the capacitance of the sample are evaluated as follows. First, alternating current impedance is measured, and the result is then analyzed by using an equivalent circuit illustrated in Fig. 1. The alternating current impedance can be measured in a NaCl solution having a concentration of 5% by mass by using a platinum electrode as a reference electrode, as illustrated in Fig. 2. In this measurement, the measurement frequency is set to 100 kHz to 10 Hz in order to confirm that the effect of a dissolution reaction of aluminum or the like is not significant. The analysis is then performed by using data in a range of 10 kHz to 1 kHz, the range being included in the above.

[0024] The porous aluminum body of the present invention preferably has a hollow skeleton. With this structure, a gas can pass through both the inside and the outside of the skeleton, and thus the porous aluminum body can be used as a heat transfer material having a good heat-exchange efficiency. Such a porous aluminum body having a hollow skeleton can be produced by a plating method in which a surface of a resin body having a three-dimensional network structure is coated with aluminum by electrolytic plating.

[0025] According to the porous aluminum body of the present invention, aluminum contained in the porous aluminum body preferably has a purity of 99.7% by mass or more. In this case, the porous aluminum body can be used as a heat transfer material having a higher thermal conductivity. In order to achieve a purity of 99.7% by mass or more of aluminum, the purity of aluminum used as an anode in the plating method may be 99.7% by mass or more. In this method, the purity of aluminum contained in the porous aluminum body can be increased to 99.9% by mass or more, and further increased to 99.99% by mass or more.

[0026] In the step of performing electrolytic plating, the surface of a resin body having a three-dimensional network structure may be subjected to a conductivity-imparting treatment such as carbon powder coating or plating of Sn or Ni. Note that the purity of aluminum represents a purity determined by excluding the material used in the conductivity-imparting treatment, such as carbon, Sn, or Ni.

[0027] The porous aluminum body according to the present invention preferably has a weight per volume of 0.1 g/cm³ or more and 1.0 g/cm³ or less. When the weight per volume of the porous aluminum body is 0.1 g/cm³ or more and 1.0 g/cm³ or less, the porous aluminum body can be used as a heat transfer material having a very large specific surface area and a good heat-exchange efficiency. The weight per volume of the porous aluminum body is more preferably 0.1 g/cm³ or more and 0.6 g/cm³ or less, and still more preferably 0.1 g/cm³ or more and 0.4 g/cm³ or less.

[0028] In order to obtain a porous aluminum body having a weight per volume in the above range, the amount of aluminum film formed, by the plating method, on the surface of the resin body having a three-dimensional network structure may be appropriately adjusted.

<Method for producing porous aluminum body>

[0029] As described above, the porous aluminum body according to the present invention can be produced by a plating method using a molten-salt bath. Specifically, a resin body composed of a urethane foam or the like and having a three-dimensional network structure provided with continuous pores (hereinafter, also simply referred to as "resin body") is used as a core material, a conductivity-imparting treatment is performed on the resin body, and electrolytic plating of aluminum is then performed in a molten-salt bath. Subsequently, the resulting resin structure having an aluminum film thereon is heat-treated so that the resin is removed by being burnt away. Thus, a porous aluminum body in which only a metal layer is left can be produced.

[0030] A method for producing a porous aluminum body according to the present invention will now be described in more detail.

(Preparation of resin body having three-dimensional network structure)

[0031] First, a resin body having a three-dimensional network structure and continuous pores is prepared. Any resin can be selected as the material of the resin body. Examples of the material include resin foam bodies composed of polyurethane, melamine, polypropylene, polyethylene, or the like.

[0032] Urethane foams and melamine foams can be preferably used as the resin foam bodies because they have high porosities, pore continuity, and good thermal decomposition properties. Urethane foams are preferable from the viewpoint of uniformity of pores, availability, etc., and from the viewpoint that a foam having a small pore diameter is obtained.

[0033] A resin body often contains residues such as a foaming agent and an unreacted monomer in the process of producing the foam. Therefore, a washing treatment is preferably performed for the subsequent steps. The resin body serving as a skeleton three-dimensionally forms a network, thereby forming continuous pores as a whole. The skeleton of a urethane foam has a substantially triangular shape in a cross section perpendicular to a direction in which the skeleton extends.

[0034] The resin foam body preferably has a porosity of 80% to 98% and a pore diameter of 420 to 4,230 μm .

[0035] The porosity is defined by the following formula:

$$\text{Porosity} = (1 - (\text{weight of porous material [g]} / (\text{volume of porous material [cm}^3\text{]} \times \text{density of raw material})) \times 100 [\%]$$

[0036] The pore diameter is determined by magnifying a surface of the resin body by means of a photomicrograph or the like, counting the number of pores per inch (25.4 mm) as the number of cells, and calculating an average of the pore diameter as mean pore diameter = 25.4 mm/the number of cells.

(Impartation of electrical conductivity to surface of resin body)

[0037] In order to coat a surface of a resin body with aluminum by electrolytic plating, the surface of the resin body is subjected to a conductivity-imparting treatment in advance. The conductivity-imparting treatment is not particularly limited as long as a layer having electrical conductivity can be provided by the treatment on the surface of the resin body. It is possible to select any method such as electroless plating of a conductive metal such as nickel, vapor deposition or sputtering of aluminum or the like, or application of a conductive coating material containing conductive particles such as carbon particles.

[0038] A method for imparting conductivity by performing a sputtering process of aluminum and a method for imparting conductivity to a surface of a resin body by using carbon particles as conductive particles will now be described as examples of the conductivity-imparting treatment.

-Sputtering of aluminum-

[0039] A sputtering process using aluminum is not particularly limited as long as aluminum is used as a target, and can be performed by an ordinary method. For example, a resin body is attached to a substrate holder, and a direct-current voltage is then applied between the holder and a target (aluminum) while an inert gas is introduced. The ionized inert gas is thereby caused to collide with aluminum, and sputtered aluminum particles are deposited on the surface of the resin body to form a sputtered film composed of aluminum. The sputtering process is preferably conducted at a temperature at which the resin body does not melt, specifically at about 100°C to 200°C, and preferably at about 120°C to 180°C.

-Carbon coating-

[0040] First, a carbon coating material serving as a conductive coating material is prepared. A suspension serving as the conductive coating material preferably contains carbon particles, a binder, a dispersant, and a dispersion medium. In order to uniformly apply the conductive particles, it is necessary that the suspension maintain a uniformly suspended state. For this purpose, the suspension is preferably maintained at 20°C to 40°C. This is because when the temperature of the suspension is lower than 20°C, the uniformly suspended state is impaired, and only the binder may be concentrated on a surface of a skeleton forming a network structure of a porous resin body to form a layer of the binder. In this case, the applied carbon particle layer is easily separated, and it is difficult to form a metal plating layer that strongly adheres to the carbon particle layer. On the other hand, when the temperature of the suspension exceeds 40°C, the amount of dispersant evaporated is large. Accordingly, with the lapse of the coating process time, the suspension is concentrated, and the amount of carbon applied tends to vary. The carbon particles preferably have a particle diameter of 0.01 to 5 μm, and more preferably 0.01 to 2 μm. When the particle diameter is excessively large, the carbon particles may clog cells of the resin body, and disturb flat and smooth plating. When the particle diameter is excessively small, it is difficult to ensure sufficient electrical conductivity.

[0041] The carbon particles can be applied onto a resin body by immersing the target resin body in the suspension, and conducting squeezing and drying.

(Formation of aluminum film on surface of resin body)

[0042] A plating method using a molten-salt bath is employed as a method for forming an aluminum film on a surface of a resin body.

-Molten salt plating-

[0043] Electrolytic plating is conducted in a molten salt to form an aluminum film on a surface of a resin body.

[0044] By conducting aluminum plating in a molten-salt bath, an aluminum film having a large thickness can be uniformly formed particularly on the surface of a complex skeleton structure, such as a resin body having a three-dimensional network structure. A direct current is supplied between the resin body having a surface to which electrical conductivity is imparted, the resin body serving as a cathode, and aluminum serving as an anode in a molten salt.

[0045] The molten salt may be an organic molten salt that is a eutectic salt of an organohalide and an aluminum halide or an inorganic molten salt that is a eutectic salt of an alkali metal halide and an aluminum halide. When an organic molten-salt bath that melts at a relatively low temperature is used, electrolytic plating can be performed without decomposition of a resin body serving as a base. An imidazolium salt, a pyridinium salt, or the like can be used as the organohalide. Specifically, 1-ethyl-3-methylimidazolium chloride (EMIC) and butylpyridinium chloride (BPC) are preferred.

[0046] Mixing of moisture or oxygen into the molten salt degrades the molten salt. Therefore, the plating is preferably conducted in an inert gas atmosphere such as nitrogen or argon in a closed environment.

[0047] A bath of a molten salt containing nitrogen is preferred as the molten-salt bath. Among such bathes, an imidazolium salt bath is preferably used. In the case where a salt that melts at a high temperature is used as a molten salt, the rate of dissolution or decomposition of a resin in the molten salt is higher than the rate of the growth of a plating film, and thus a plating film cannot be formed on the surface of the resin body. An imidazolium salt bath can be used even at a relatively low temperature without affecting a resin. A salt containing an imidazolium cation having alkyl groups at the 1- and 3-positions is preferably used as an imidazolium salt. In particular, aluminum chloride-1-ethyl-3-methylimidazolium chloride (AlCl_3 -EMIC) molten salts are most preferably used because they have high stability and are not easily decomposed. Plating on a urethane resin foam or a melamine resin foam can be performed by using the molten salt bath. The temperature of the molten salt bath is 10°C to 100°C, and preferably 25°C to 45°C. With a decrease in the temperature of the molten salt bath, the current density range for plating becomes narrow, and plating on the entire surface of a resin body becomes difficult. When the temperature of the molten salt bath is a high temperature of more than 100°C, the shape of the resin body serving as a base tends to be deformed. Through the above steps, an aluminum-resin structure including the resin body serving as a core of the skeleton is prepared.

(Removal of resin)

[0048] The aluminum-resin structure prepared as described above is heat-treated by being heated at 500°C or higher in a nitrogen atmosphere, air, or the like. The resin is thereby removed by being burnt away, and a porous aluminum body is thus obtained. It was found that, in order to produce the porous aluminum body of the present invention, it is effective to add an improvement to this step, which has been hitherto performed. Specifically, a method described below is employed.

-Treatment of plating solution adhering to resin structure-

[0049] A plating solution adheres to the surface of the resin body prepared as described above, the resin body having an aluminum film on the surface thereof. Therefore, a water washing treatment is performed, and a heating treatment is then performed.

[0050] In this step, the plating solution is not sufficiently drained and the water washing step is subsequently performed. Thus, a porous aluminum body whose skeleton has fine irregularities on the surface thereof can be obtained. It is believed that this is because the plating solution containing the molten salt reacts with water to thereby generate heat, and aluminum and water react with each other on the surface of the aluminum film to form boehmite. In general, a dehydration reaction of boehmite occurs at 450°C or higher, and boehmite is transformed into γ -alumina having micropores. Also in the present invention, during combustion removal of a resin from a resin structure, the resin structure is exposed to a high temperature of 500°C or higher. Consequently, boehmite produced as described above is transformed into γ -alumina, thereby forming fine irregularities on the surface of the skeleton.

[0051] In order to obtain, by this method, a porous aluminum body whose skeleton has fine irregularities on the surface thereof, the water washing treatment is preferably performed in a state where the amount of plating solution adhering to the resin structure becomes 20 to 2,000 mL/m². The amount of plating solution adhering to the resin structure is more preferably 200 to 2,000 mL/m², and still more preferably 1,000 to 2,000 mL/m².

-Water washing treatment of resin structure-

[0052] Even in the case where the plating solution is sufficiently removed in the treatment of the plating solution adhering to the resin structure, a porous aluminum body whose skeleton has fine irregularities on the surface thereof

can be produced as follows. As described above, a water washing treatment is performed in order to remove a plating solution adhering to a resin body having an aluminum film on the surface thereof. In this step, heat treatment for removing the resin may be performed without sufficiently removing water adhering to the resin structure. It is believed that, also in this case, in the step of heating the resin structure, aluminum and water react with each other on the surface of the aluminum film at about 80°C to produce boehmite, and the boehmite is then transformed into γ -alumina having micropores by being further heated.

[0053] In order to obtain, by this method, a porous aluminum body whose skeleton has fine irregularities on the surface thereof, the treatment for combustion removal of the resin is preferably performed in a state where the amount of water adhering to the resin structure becomes 10 to 1,000 mL/m². The amount of water adhering to the resin structure is more preferably 100 to 1,000 mL/m², and still more preferably 500 to 1,000 mL/m².

-Combustion removal of resin from resin structure-

[0054] Besides the two methods described above, there is a method for producing a porous aluminum body whose skeleton has fine irregularities on the surface thereof. Specifically, even in the case where the plating solution is sufficiently drained, and water that is adhered by the subsequent water washing treatment is also sufficiently removed, a subsequent step of combustion removal of a resin may be performed in an atmosphere containing a large amount of water, i.e., having a high dew point. For this purpose, for example, heat treatment may be performed by heating to 500°C or higher while supplying humidified air. It is believed that, also in this case, water supplied in the atmosphere in which the heat treatment is performed and aluminum react with each other at about 80°C to produce boehmite, and the boehmite is then transformed into γ -alumina having micropores by being further heated.

[0055] In order to obtain, by this method, a porous aluminum body whose skeleton has fine irregularities on the surface thereof, the dew-point temperature of the atmosphere in the step of combustion removal of a resin is preferably 0°C to 60°C. The dew-point temperature is more preferably 20°C to 60°C, and still more preferably 40°C to 60°C.

<Heat transfer material and heat exchange device>

[0056] By using the porous aluminum body of the present invention as a heat transfer material, a heat transfer material having a very large specific surface area, a good heat-exchange efficiency, and a low pressure drop of a gas can be obtained. In addition, since a heat exchange device produced by using the porous aluminum body of the present invention as a heat transfer material has a very high heat-exchange efficiency, the size of the heat exchange device can be reduced as compared with an existing heat exchange device.

[0057] The heat exchange device is not particularly limited as long as the porous aluminum body of the present invention is thermally connected to a heating element or a cooling element and used as a heat transfer material, and the heat exchange device includes means for transferring heat transferred to the porous aluminum body to another medium by air blowing or the like.

[0058] An example of the heat exchange device is the use of the porous aluminum body of the present invention as a heat dissipation material of a semiconductor device. For example, the porous aluminum body of the present invention can be used instead of a so-called existing heat sink or the like. Specifically, cooling can be efficiently performed by providing the porous aluminum body of the present invention on a heating element and supplying wind with a fan or the like.

[0059] Another example of the heat exchange device is an air conditioner or the like. In this case, the porous aluminum body of the present invention may be used instead of a fin provided on a surface of a heat transfer tube through which a cooling medium or a heating medium passes. By supplying air to the porous aluminum body, heat transferred from the heat transfer tube can be transferred to air.

[0060] Means for providing a porous aluminum body on a surface of a heat transfer tube is not particularly limited. For example, the porous aluminum body can be joined by using flux and a brazing material containing an aluminum alloy powder or the like. In such a case, the thickness of the porous aluminum body used as a heat transfer material is not particularly limited, and can be appropriately changed in accordance with the design of the heat exchange device. A porous aluminum body having any thickness can be obtained by appropriately changing the thickness of the resin body used as a starting material in the production by the plating method.

[0061] The porous aluminum body of the present invention can be provided not only on an outer surface of the heat transfer tube but also on an inner surface of the heat transfer tube. With this structure, heat from a cooling medium (or a heating medium) that passes through the heat transfer tube can be more efficiently transferred to the outside.

EXAMPLES

[0062] The present invention will be described in more detail using Examples. However, these Examples are only illustrative, and an apparatus for producing an aluminum powder of the present invention and the like are not limited

thereto. It is to be understood that the scope of the present invention is defined by the description of Claims and includes equivalents of the description in Claims and all modifications within the scope of Claims.

[EXAMPLE 1]

(Formation of electrically conductive layer)

[0063] A urethane foam having a porosity of 97%, a number of cells of 10 per inch, a pore diameter of about 2,540 μm , and a thickness of 10 mm was prepared as a resin body and cut into a rectangle of 80 mm x 50 mm. Aluminum was deposited on the surface of the polyurethane foam by sputtering with a weight per volume of 10 g/m² to form an electrically conductive layer.

(Molten salt plating)

[0064] The urethane foam having the electrically conductive layer on the surface thereof was set, as a workpiece, to a fixture having a power-supplying function. The fixture to which the workpiece was set was then placed in a glove box in an argon atmosphere having a low water content (dew point: -30°C or lower) and immersed in a molten salt aluminum plating bath (prepared by adding 0.5 g/L of 1,10-phenanthroline to 33 mol% EMIC-67 mol% AlCl_3) at a temperature of 45°C. The fixture to which the workpiece was set was connected to the cathode side of a rectifier, and an aluminum plate (purity: 99.99% by mass) serving as a counter electrode was connected to the anode side.

[0065] Plating was conducted by supplying a direct current at a current density of 6 A/dm² for 60 minutes. As a result, a structure in which an aluminum film was formed at a mass of 0.15 g/cm³ on the surface of the urethane foam was obtained. Stirring was performed with a stirrer using a rotor composed of Teflon (registered trademark). Note that the current density is a value calculated on the basis of the apparent area of the urethane foam.

(Removal of resin)

[0066] The structure prepared as described above was taken from the plating bath, and a water washing treatment was conducted in a state where the amount of plating solution adhering to the structure became 1,500 mL/m². After the water washing treatment, the structure was sufficiently dried, and in a state where the amount of water adhering to the structure became 6 mL/m², heat treatment was conducted at 600°C for 30 minutes in air having a dew-point temperature of -15°C. Through this step, the resin was removed by being burnt away. Thus, a porous aluminum body 1 of the present invention (purity: 99.99% by mass) was obtained.

-Evaluation-

<Specific surface area>

[0067] The specific surface area of the porous aluminum body 1 was measured by the capacitance method described above. Specifically, a plurality of aluminum plates having a purity of 99.99% by mass and having known surface areas were prepared. The capacitance of each of the aluminum plates was evaluated, and a calibration curve of "capacitance" versus "surface area" was prepared. The capacitance of the porous aluminum body was then evaluated. Thus, the surface area of the porous aluminum body was determined by a calibration curve method.

[0068] Table I shows the results.

<Observation with microscope>

[0069] The porous aluminum body 1 was observed with an electron microscope. A large number of fine irregularities were formed on the surface of the porous aluminum body 1.

[EXAMPLE 2]

[0070] A porous aluminum body 2 was obtained by the same method as that used in Example 1 except that, in the method for producing a porous aluminum body in Example 1, the water washing treatment was conducted in a state where the amount of plating solution adhering to the structure became 10 mL/m², and subsequently, in a state where the amount of water adhering to the structure was 800 mL/m², heat treatment was conducted in air having a dew-point temperature of -10°C.

[0071] The evaluation was conducted as in Example 1. Table I shows the results.

[EXAMPLE 3]

[0072] A porous aluminum body 3 was obtained by the same method as that used in Example 1 except that, in the method for producing a porous aluminum body in Example 1, the water washing treatment was conducted in a state where the amount of plating solution adhering to the structure became 6 mL/m², and subsequently, in a state where the amount of water adhering to the structure was 5 mL/m², heat treatment was conducted in air having a dew-point temperature of 58°C.

[0073] The evaluation was conducted as in Example 1. Table I shows the results.

[EXAMPLE 4]

[0074] A porous aluminum body 4 was obtained as in Example 1 except that, in the method for producing a porous aluminum body in Example 1, a urethane foam having a number of cells of 30 per inch was used.

[0075] The evaluation was conducted as in Example 1. Table I shows the results.

[EXAMPLE 5]

[0076] A porous aluminum body 5 was obtained as in Example 2 except that, in the method for producing a porous aluminum body in Example 2, a urethane foam having a number of cells of 30 per inch was used.

[0077] The evaluation was conducted as in Example 1. Table I shows the results.

[EXAMPLE 6]

[0078] A porous aluminum body 6 was obtained as in Example 3 except that, in the method for producing a porous aluminum body in Example 3, a urethane foam having a number of cells of 30 per inch was used.

[0079] The evaluation was conducted as in Example 1. Table I shows the results.

[COMPARATIVE EXAMPLE 1]

[0080] A porous aluminum body 7 was obtained by the same method as that used in Example 1 except that, in the method for producing a porous aluminum body in Example 1, the water washing treatment was conducted in a state where the amount of plating solution adhering to the structure became 10 mL/m², and subsequently, in a state where the amount of water adhering to the structure was 4 mL/m², heat treatment was conducted in air having a dew-point temperature of -10°C.

[0081] The evaluation was conducted as in Example 1. Table I shows the results.

[COMPARATIVE EXAMPLE 2]

[0082] A porous aluminum body 8 was obtained by the same method as that used in Example 4 except that, in the method for producing a porous aluminum body in Example 4, the water washing treatment was conducted in a state where the amount of plating solution adhering to the structure became 10 mL/m², and subsequently, in a state where the amount of water adhering to the structure was 4 mL/m², heat treatment was conducted in air having a dew-point temperature of -10°C.

[0083] The evaluation was conducted as in Example 1. Table I shows the results.

[COMPARATIVE EXAMPLE 3]

[0084] Duocel (registered trademark): material A6061, manufactured by ERG Aerospace Corporation, the Duocel being produced by a casting method, was prepared as a porous aluminum body 9.

[0085] The evaluation was conducted as in Example 1. Table I shows the results.

[Table I]

	Production process			Evaluation			
	Amount of plating solution adhering to structure (mL/m ²)	Amount of water adhering to structure (mL/m ²)	Dew-point temperature of heat-treatment atmosphere (°C)	Number of cells X (per inch)	Specific surface area Y (m ² /m ³)	Numerical value a	Fine irregularities on skeleton surface
Example 1	1500	6	-15	10	1460	806	Formed
Example 2	10	800	-10	10	1160	650	Formed
Example 3	6	5	58	10	580	305	Formed
Example 4	1500	6	-15	30	4700	780	Formed
Example 5	10	800	-10	30	3750	615	Formed
Example 6	6	5	58	30	1620	270	Formed
Comparative Example 1	10	4	-10	10	150	90	Not formed
Comparative Example 2	10	4	-10	30	470	82	Not formed
Comparative Example 3	-	-	-	10	100	52	Not formed

Claims

1. A porous aluminum body comprising aluminum as a main component, wherein the porous aluminum body has a three-dimensional network structure and has a specific surface area (Y) represented by a (Formula) below:

$$Y = a \times \exp(0.06X) \quad (\text{Formula})$$

(where, in the (Formula), Y represents a specific surface area [m²/m³], X represents the number of cells [per inch], and a represents a number of 100 or more and 1,000 or less.)

2. The porous aluminum body according to Claim 1, wherein the porous aluminum body has a hollow skeleton.
3. The porous aluminum body according to Claim 1 or 2, wherein aluminum contained in the porous aluminum body has a purity of 99.7% by mass or more.
4. The porous aluminum body according to any one of Claims 1 to 3, wherein a weight per volume of the porous aluminum body is 0.1 g/cm³ or more and 1.0 g/cm³ or less.
5. A heat transfer material comprising the porous aluminum body according to any one of Claims 1 to 4.
6. A heat exchange device comprising the porous aluminum body according to any one of Claims 1 to 4.

FIG. 1

EQUIVALENT CIRCUIT

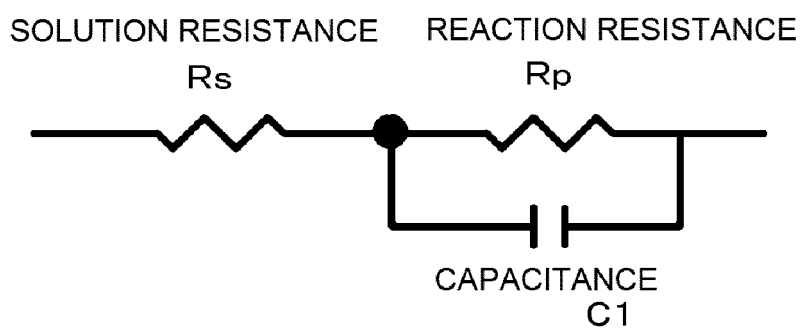
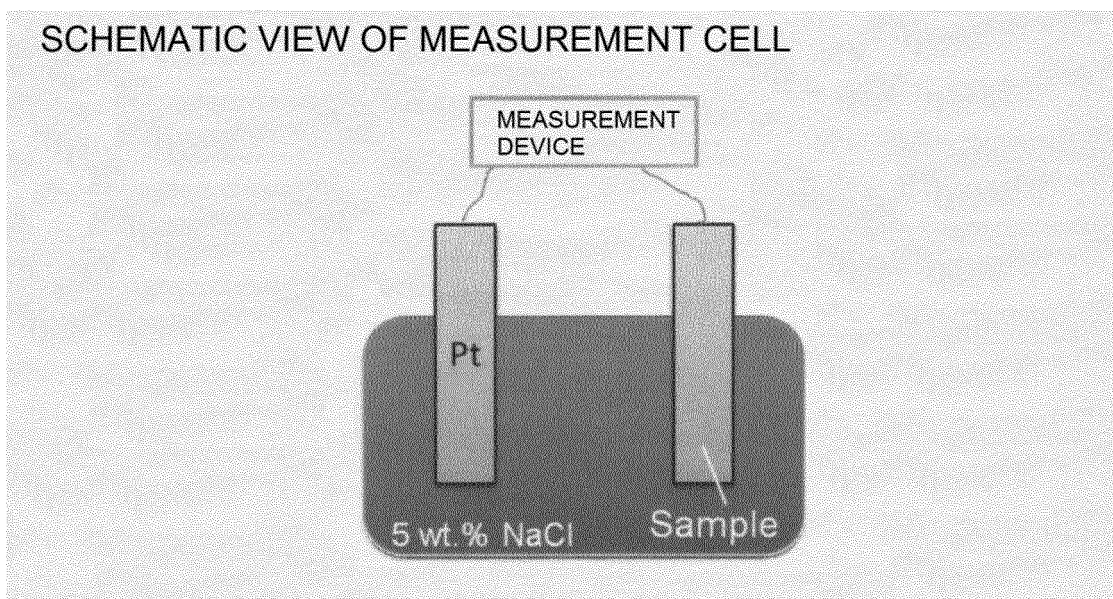


FIG. 2

SCHEMATIC VIEW OF MEASUREMENT CELL



INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2013/083703

A. CLASSIFICATION OF SUBJECT MATTER

C22C1/08(2006.01)i, B22F3/11(2006.01)i, B22F5/10(2006.01)i, F28F21/08(2006.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

C22C1/08, B22F3/11, B22F5/10, F28F21/08

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Jitsuyo Shinan Koho 1922-1996 Jitsuyo Shinan Toroku Koho 1996-2014

Kokai Jitsuyo Shinan Koho 1971-2014 Toroku Jitsuyo Shinan Koho 1994-2014

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	JP 2011-214082 A (Bando Chemical Industries, Ltd.), 27 October 2011 (27.10.2011), claims; paragraph [0047] (Family: none)	1-6

☐ Further documents are listed in the continuation of Box C.

☐ See patent family annex.

* Special categories of cited documents:

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"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search
05 March, 2014 (05.03.14)

Date of mailing of the international search report
18 March, 2014 (18.03.14)

Name and mailing address of the ISA/
Japanese Patent Office

Authorized officer

Facsimile No.

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REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- JP 7190664 A [0003] [0007]
- JP 2012124391 A [0004] [0007]
- JP 2011225950 A [0009]