

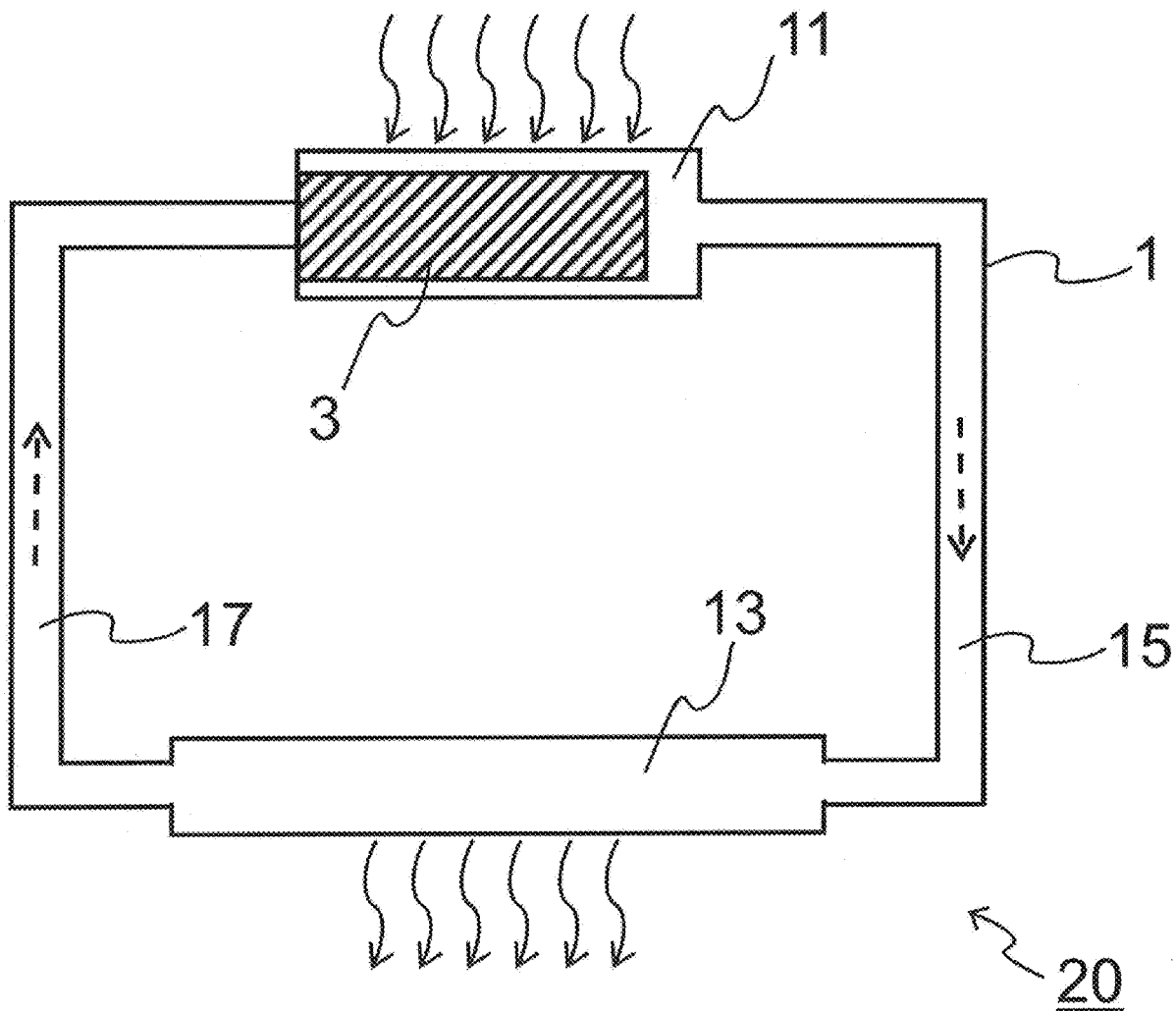


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MORITA et al.(10) **Pub. No.: US 2025/0067521 A1**(43) **Pub. Date: Feb. 27, 2025**(54) **WICK AND HEAT TRANSPORT DEVICE****Publication Classification**(71) Applicant: **Murata Manufacturing Co., Ltd.**,
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CPC **F28D 15/046** (2013.01)(57) **ABSTRACT**(21) Appl. No.: **18/944,213**(22) Filed: **Nov. 12, 2024**(30) **Foreign Application Priority Data**

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A wick used for heat transport, the wick including a material containing a nanofiber and/or a two-dimensional substance represented by: MQ_aO_b , wherein M is at least one element selected from Groups 3, 4, 5, 6, or 7, Q is at least one element selected from Groups 12, 13, 14, 15, or 16, and excluding O, a is more than 0 but not more than 2, and b is more than 0 but not more than 2.



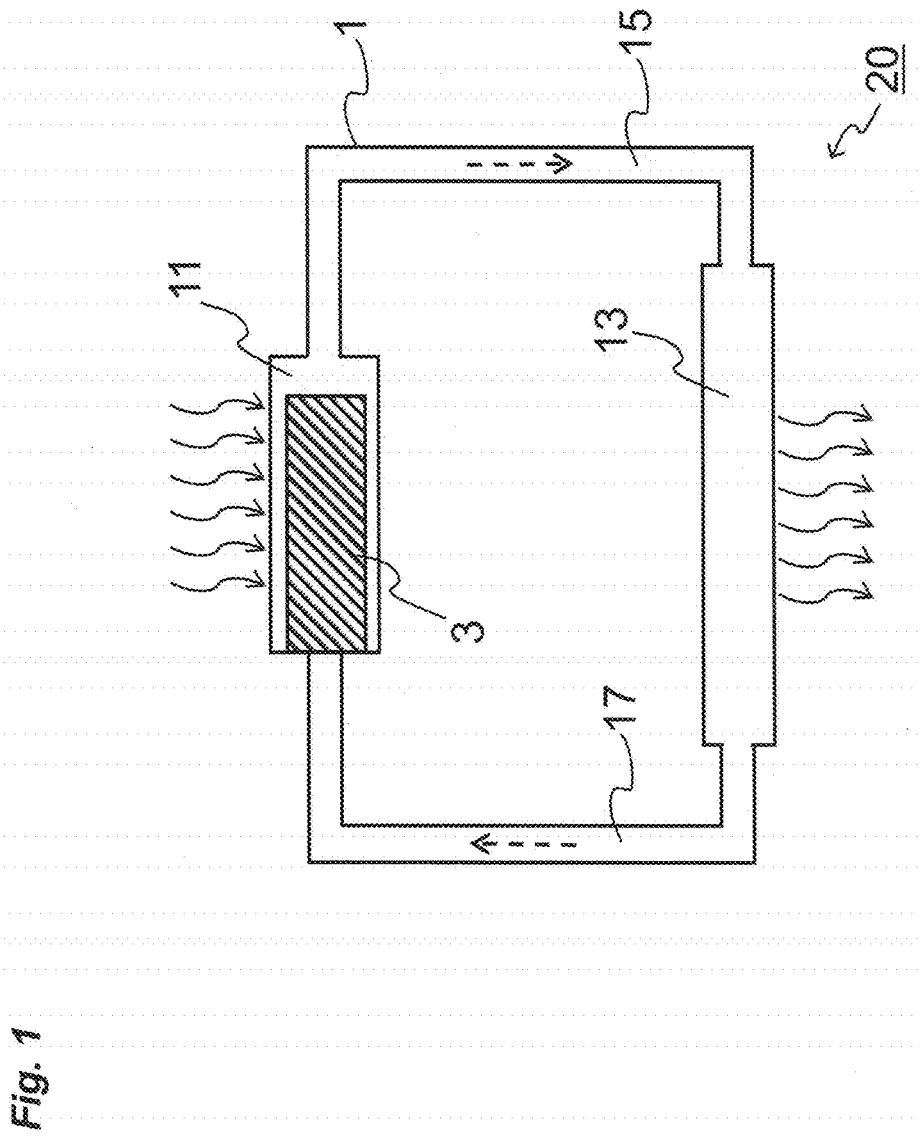
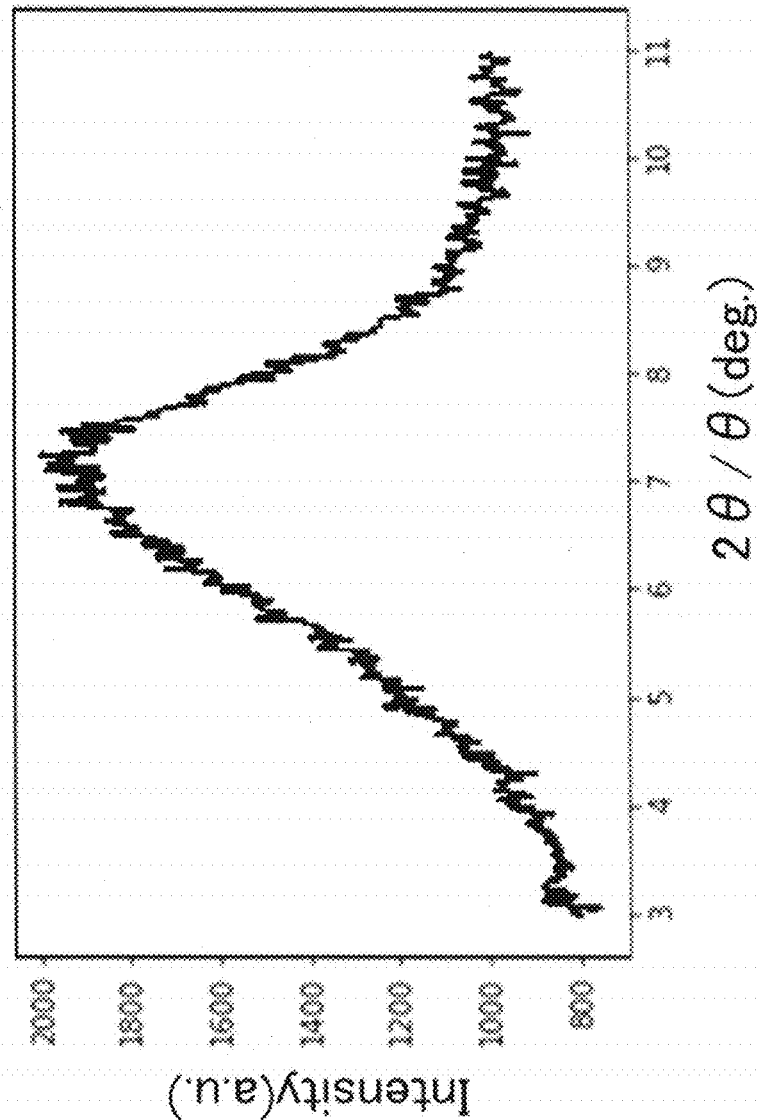


Fig. 2



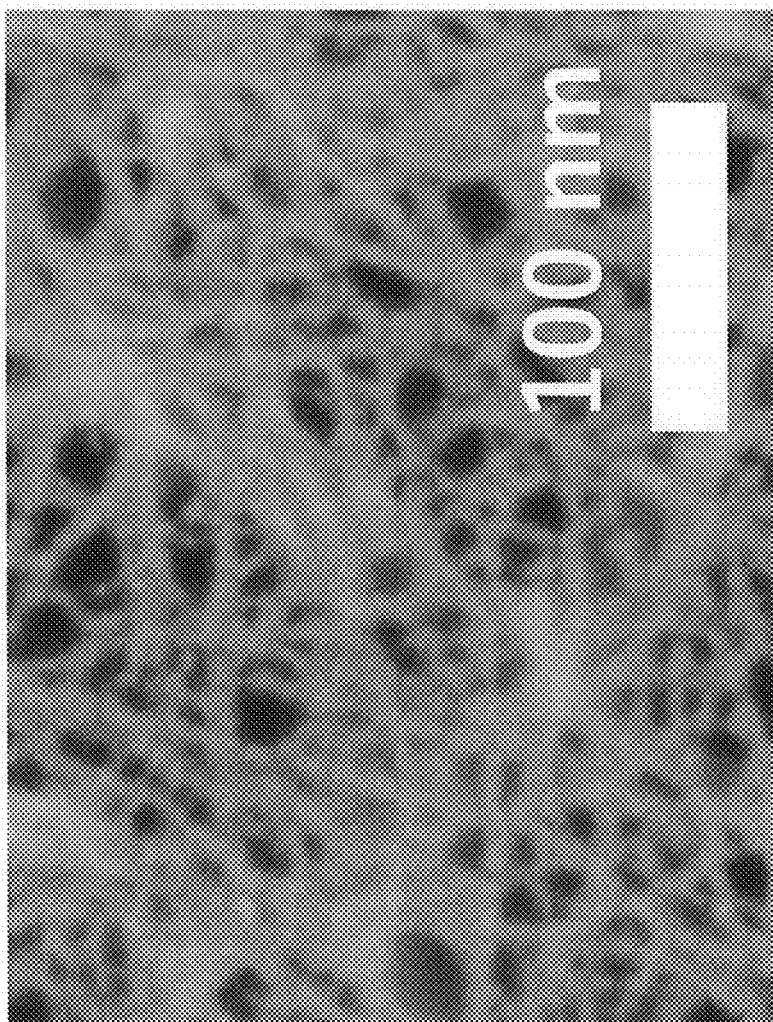


Fig. 3

WICK AND HEAT TRANSPORT DEVICE

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] The present application is a continuation of International application No. PCT/JP2023/017973, filed May 12, 2023, which claims priority to Japanese Patent Application No. 2022-079566, filed May 13, 2022, the entire contents of each of which are incorporated herein by reference.

TECHNICAL FIELD

[0002] The present disclosure relates to a wick and a heat transport device, and more particularly to a wick used for heat transport and a heat transport device utilizing a phase change of a working fluid.

BACKGROUND ART

[0003] Conventionally, a heat transport device utilizing a phase change (more particularly, evaporation and condensation) of a working fluid such as a heat pipe or a vapor chamber is known. In such a heat transport device, a wick that transfers a working fluid in a liquid state by a capillary force (suction force due to capillary phenomenon) is used.

[0004] For example, Patent Document 1 describes that a sintered body of metal particles having an average particle diameter of not less than 20 μm and not more than 200 μm is used as a wick. For example, Patent Document 2 describes that a fiber-containing porous body in which a carbon porous body is filled in at least a part of a fiber structure containing carbon fibers and/or oxidized fibers, the fiber-containing porous body having at least one peak in a pore diameter region of 10 μm or less in the pore diameter distribution of the carbon porous body is used as the wick.

[0005] Patent Document 1: JP-A-2022-27310

[0006] Patent Document 2: JP-A-2020-112326

[0007] Non Patent Document 1: Hussein O. Badr, et al., “Bottom-up, scalable synthesis of anatase nanofilament-based two-dimensional titanium carbo-oxide flakes”, Materials Today (2021) <https://doi.org/10.1016/j.mattod.2021.10.033>

SUMMARY OF THE DISCLOSURE

[0008] The heat transport device as described above uses a housing having at least partial thermal conductivity, and has a configuration in which the wick and a working fluid are disposed and sealed in the housing. In the housing, the working fluid evaporates in a relatively high temperature portion to which heat is supplied from the outside, the working fluid in a gaseous state moves in the housing and condenses in a relatively low temperature portion to release heat to the outside, and the working fluid in a liquid state is transferred (returned) to the relatively high temperature portion by the capillary force of the wick.

[0009] In recent years, the heat transport device is required to further improve heat transport performance due to the downsizing and the like of an electronic device in which the heat transport device can be incorporated. Conventionally, the speed at which the working fluid in the liquid state is transferred by the capillary force of the wick is lower than the speed at which the working fluid in the gaseous state moves in the housing, and the heat transport performance of the heat transport device can be limited by the speed at which the working fluid in the liquid state is transferred by

the capillary force of the wick. In order to improve the heat transport performance of the heat transport device, the transfer speed of the working fluid in the liquid state in the wick is desirably higher.

[0010] An object of the present disclosure is to provide a novel wick having a high transfer speed of a working fluid in a liquid state. Another object of the present disclosure is to provide a novel heat transport device using such a wick.

[0011] According to one gist of the present disclosure, a wick used for heat transport, the wick comprising a material containing a nanofiber and/or a two-dimensional substance represented by the following formula:



[0012] wherein

[0013] M is at least one element selected from Groups 3, 4, 5, 6, or 7,

[0014] Q is at least one element selected from Groups 12, 13, 14, 15, or 16, and excluding O,

[0015] a is not less than 0 and not more than 2, and

[0016] b is more than 0 but not more than 2.

[0017] According to another aspect of the present disclosure, there is provided a heat transport device utilizing a phase change of a working fluid, the heat transport device comprising: a housing having a space therein; the wick disposed in the housing; and the working fluid sealed in the housing in a contactable state with the wick.

[0018] According to the present disclosure, a novel wick having a high transfer speed of a working fluid in a liquid state is provided. Furthermore, according to the present disclosure, a novel heat transport device using such a wick is provided.

BRIEF DESCRIPTION OF THE DRAWINGS

[0019] FIG. 1 is a schematic cross-sectional view of a heat transport device according to one embodiment of the present disclosure.

[0020] FIG. 2 shows an XRD pattern of a material (TiCo) produced in Example 1.

[0021] FIG. 3 shows an FE-SEM image of a material (TiCo) produced in Example 1.

DETAILED DESCRIPTION

[0022] Hereinafter, a wick and a heat transport device in embodiments of the present disclosure will be described in detail, but the present disclosure is not limited to these embodiments.

First Embodiment: Wick

[0023] The present embodiment relates to a wick. In the present disclosure, the “wick” means a member used for heat transport. More specifically, the “wick” means a member capable of transferring a working fluid in a liquid state by a capillary force.

[0024] In the present embodiment, the wick includes a material containing a nanofiber and/or a two-dimensional substance. In the present disclosure, simply referring to the “material” means “a material containing a nanofiber and/or a two-dimensional substance” (in other words, a material containing at least one of a nanofiber and a two-dimensional substance). In the present embodiment, the material containing a nanofiber and/or a two-dimensional substance typically means a material that is solid and does not contain

a binder or the like (for example, a polymer). The material containing a nanofiber and/or a two-dimensional substance can mean, in a narrow sense, a material substantially composed of at least one of a nanofiber and a two-dimensional substance (which may contain other objects or impurities or the like that may be inevitably mixed). However, the material containing a nanofiber and/or a two-dimensional substance is not limited thereto.

[0025] The material contained in the wick of the present embodiment is a nanofiber (or nanofilament, etc.) of a predetermined material (substance) and/or a two-dimensional substance. The predetermined material that can be used in the present embodiment is represented by the following Formula (1):



[0026] wherein M is at least one element selected from the group consisting of Groups 3, 4, 5, 6 or 7, and may contain a so-called early transition metal, for example, at least one element selected from the group consisting of Sc, Ti, Zr, Hf, V, Nb, Ta, Cr, Mo and Mn, and preferably at least one element selected from the group consisting of Ti, V, Cr, Mo and Mn,

[0027] Q is at least one element (excluding O) selected from the group consisting of Groups 12, 13, 14, 15, or 16, and may contain, for example, at least one element selected from the group consisting of B, C, N, Si, P, and S,

[0028] a is not less than 0 and not more than 2, and

[0029] b is more than 0 but not more than 2.

[0030] Hereinafter, the predetermined material is also simply referred to as “MQO”. Examples of MQO include materials represented by formulas such as TiO_2 , $TiCO$, $TiCON$, VO_2 , VCO , $VCON$, CrO_2 , $CrCO$, $CrCON$, MoO_2 , $MoCO$, $MoCON$, MnO_2 , $MnCO$, and $MnCON$. For example, in Formula (1), M may be Ti, and the Q may be C. For example, in Formula (1), a may not be 0.

[0031] Typically, the predetermined material may have a peak in a range in which a diffraction angle 2θ is not less than 2° and not more than 100° in an X-ray diffraction (XRD) pattern.

[0032] MQO has a crystal structure different from that of a hexagonal system. Although the present embodiment is not bound by any theory, it can be considered that the crystal structure of MQO is an anatase type, a lepidocrocite type, or a mixture thereof at present. For example, the crystal structure of MQO may be a lepidocrocite type.

[0033] MQO can be produced using a first raw material and a second raw material, for example, as follows. The first raw material contains at least M, the second raw material contains at least Q, and the first raw material and the second raw material can react in a protic solvent to generate MQO.

[0034] As the first raw material, a material represented by the following Formula (2) can be used:



[0035] wherein M is as described above,

[0036] A^1 is at least one element selected from the group consisting of Groups 12, 13, 14, 15, or 16, and may contain, for example, at least one element selected from the group consisting of B, C, N, O, Si, P, and S, and

[0037] c and d are each independently not less than 1 and not more than 5.

[0038] However, the material represented by Formula (2) needs to be different from MQO of the product. Typically, the material represented by Formula (2) may not have a peak in a range in which a diffraction angle 2θ is not less than 2° and not more than 10° in an X-ray diffraction (XRD) pattern.

[0039] Examples of the first raw material represented by Formula (2) include TiB_2 , TiB , TiC , TiN , TiO_2 , Ti_5Si_3 , Ti_2SbP , VO_2 , V_2O_4 , NbC , Nb_2O_5 , MoO_2 , MoO_3 , MoS_2 , MnO_2 , Mn_3O_4 , and $MnCO_3$. MnO_2 that can be used as the first raw material has a peak in the vicinity of $2\theta=13^\circ$ and does not have a peak in the range where 2θ is not less than 2° and not more than 10° in the XRD pattern.

[0040] Alternatively, or in addition to the above, a material represented by the following Formula (3) (hereinafter, also simply referred to as “MAX phase” or “MAX raw material”) can be used as the first raw material:



[0041] wherein M is as described above,

[0042] X is at least one element selected from the group consisting of C and N,

[0043] n is not less than 1 and not more than 4,

[0044] m is more than n but not more than 5,

[0045] A^2 is at least one element selected from the group consisting of Groups 12, 13, 14, 15, or 16, is usually a Group A element, typically Group IIIA and Group IVA, and more particularly may contain at least one selected from the group consisting of Al, Ga, In, Tl, Si, Ge, Sn, Pb, P, As, S, and Cd, and is preferably Al.

[0046] The MAX phase has a crystal structure in which a layer constituted by A^2 atoms is located between two layers represented by M_mX_n (each X may have a crystal lattice located in an octahedral array of M). In the case of $m=n+1$, the MAX phase typically includes repeating units in which each one layer of X atoms is disposed in between adjacent layers of $n+1$ layers of M atoms (these are also collectively referred to as an “ M_mX_n layer”), and a layer of A^2 atoms (“ A^2 atom layer”) is disposed as a layer next to the $(n+1)$ th layer of M atoms. However, the MAX phase is not limited thereto.

[0047] Examples of the first raw material represented by Formula (3) include Ti_3AlC_2 , Ti_3GaC_2 , and Ti_3SiC_2 .

[0048] As the first raw material, the material represented by Formula (2) and the material represented by Formula (3) may be used together (for example, as a mixture).

[0049] As the second raw material, an ion-binding substance having a carbon-containing group can be used. The ion-binding substance having a carbon-containing group contains C. Examples of the ion-binding substance include ammonium salts, phosphate salts, and sulfate salts.

[0050] More specifically, a quaternary ammonium salt can be used as the second raw material. Examples of the quaternary ammonium salt include tetramethylammonium hydroxide (TMAH), tetraethylammonium hydroxide (TEAH), tetrapropylammonium hydroxide (TPAH), tetrabutylammonium hydroxide (TBAH or TBAOH), benzyltrimethylammonium hydroxide, tetrabutylammonium fluoride (TBAF), tetrabutylammonium chloride (TBACl), tetrabutylammonium bromide (TBAB), tetrabutylammonium iodide (TBAI), benzyltriethylammonium chloride (BTEAC), hexadecyltrimethylammonium bromide, cetyltrimethylammonium bromide (CTAB), benzetonium chloride, benzalkonium chloride, and cetylpyridinium chloride (CPC). Among them, TMAH and TBAOH are preferable.

[0051] Alternatively, or in addition to the above, other ion-binding substances containing P and/or S etc. may be used as the second raw material.

[0052] The protic solvent may be any solvent that can at least partially dissolve the first raw material and the second raw material, and may be particularly an aqueous solvent. As the protic solvent, water, an alcohol (for example, ethanol, 1-propanol, isopropanol), or a carboxylic acid (for example, acetic acid, formic acid) or the like is used. The aqueous solvent may be composed of water and optionally a liquid substance compatible with water (for example, a protic solvent other than water), and is preferably water.

[0053] The first raw material and the second raw material are reacted in the protic solvent. The second raw material can be added to the protic solvent in advance. The ratio of the second raw material to the total of the protic solvent and the second raw material may be, for example, 5% by mass or more, particularly 20% by mass or more, and/or may be, for example, 80% by mass or less, particularly 50% by mass or less. The first raw material can be further added to and mixed with the protic solvent to which the second raw material has been added. In such a mixture, a reaction for producing MQO proceeds. The temperature (reaction temperature) of the mixture (which may contain the reaction product) may be, for example, 15° C. or higher, particularly 40° C. or higher, and/or, for example, 100° C. or lower, particularly 80° C. or lower. A mixing time (reaction time) may, for example, be 1 day or more, particularly 2 days or more, and/or may, for example, be 10 days or less, particularly 7 days or less. The mixing can be performed, for example, by rotating and stirring a magnetic stirring bar charged into a container using a magnetic stirrer while the reaction temperature is maintained by a hot plate stirrer and a hot water bath. However, the treatment operation and conditions (temperature and time and the like) under which the reaction can proceed are not limited to the above, and may be appropriately selected according to the first raw material, the second raw material, and the protic solvent and the like to be used.

[0054] By the above reaction, MQO is generated, and can eventually grow into nanofibers of MQO, and further into nanoflakes of MQO. Without limiting the present disclosure, the resulting nanofibers of the MQO may be in the form of nanoribbons extending at nanoscale widths. A plurality of nanofibers (for example, nanoribbons) of MQO may be bonded and/or integrated with each other to grow into nanoflakes two-dimensionally extending. A plurality of MQO nanoflakes may overlap each other (for example, by van der Waals force) to form a laminate. Although the present disclosure is not bound by any theory, such generation and growth of MQO can be considered to be due to a bottom-up type synthesis reaction (see, for example, Non Patent Document 1).

[0055] In the present disclosure, MQO is a solid content. MQO can be typically a particle (or powder).

[0056] The mixture after the reaction (also referred to as a reaction mixture) may be appropriately subjected to post-treatment. Examples of the post-treatment include washing, impact application (including shear force application), drying (for example, freeze dry, heat dry), and pulverization.

[0057] The washing may be performed using a protic solvent. The same description as above may apply to the protic solvent, and the protic solvent may be washed with, for example, water or an alcohol. After washing, a separation

operation (centrifugation and/or decantation) may be performed. The washing and separation operations may be repeated until the pH of a supernatant liquid after centrifugation is, for example, 8 or less.

[0058] Optionally, washing may be performed using an aqueous solution of a metal salt instead of or in addition to the above washing. The metal salt may be, for example, a halide (fluoride, chloride, bromide, or iodide) of an alkali metal (Li, Na, or K or the like), typically LiCl, NaCl, or KCl or the like. Specifically, for example, washing may be performed using an aqueous solution of a metal salt having a molar concentration of 1 to 10. After washing, a separation operation (centrifugation and/or decantation) may be performed. Also in this case, the washing and separation operations may be repeated as necessary until the pH of the supernatant liquid after centrifugation is, for example, 8 or less.

[0059] During and/or after washing, an impact such as vibration and/or ultrasound may be applied. This makes it possible to promote the dispersion or the like of MQO particles (for example, nanofibers/nanoflakes, and so on). When the MQO particles are aggregated, they can be crushed. Such an effect is remarkably obtained when an impact is applied during washing using an aqueous solution of a metal salt (it is considered that metal cations derived from the metal salt can enter gaps of the aggregates and the aggregates can be crushed). The impact can be imparted using, for example, any one or more of a handshake, an automatic shaker, a mechanical shaker, a vortex mixer, a homogenizer, and an ultrasonic bath and the like.

[0060] Since the MQO particles are solid, a separation operation may be performed at any suitable timing to remove unwanted liquid components if present. As a final separation operation, for example, a drying operation, typically freeze drying or heat drying, may be performed. The freeze-drying may be performed, for example, by freezing a mixture containing MQO particles and a liquid component at any suitable temperature (for example, -40° C.), followed by drying under a reduced pressure atmosphere. The heat drying can be performed, for example, by drying a mixture containing MQO particles and a liquid component at a temperature of 25° C. or higher (for example, 200° C. or lower) under a normal pressure or a reduced pressure atmosphere. The pulverization is not particularly limited, but can be performed using, for example, a combination of a mortar and a pestle, or an IKA mill or the like. The pulverization may be performed after drying.

[0061] As described above, the MQO particles can be obtained as a material containing MQO. As the MQO particles, for example, nanofibers (and optionally, an aggregate of MQO nanofibers, for example, MQO nanoflakes, and these are also collectively referred to as "MQO nanofibers or the like") can be obtained.

[0062] Although MQO is represented by Formula (1), the material containing MQO (typically, MQO particles) does not need to be composed of only the constituent elements of Formula (1). Without limiting the present disclosure, a material containing MQO may optionally contain protons and/or metal cations. Although the present disclosure is not limited, the material containing MQO may optionally contain at least one selected from the group consisting of a hydroxyl group, a chlorine atom, an oxygen atom, a hydrogen atom, and a nitrogen atom as modification or termination T present on the surface. The material containing MQO

(typically, MQO particles) may have two or more layers, and at least one selected from the group consisting of ammonium ions (for example, quaternary ammonium cations) and metal cations (for example, alkali metal ions and alkaline earth metal ions) may be present between these layers.

[0063] The material containing MQO such as MQO nanofibers may contain unreacted first raw material and/or second raw material as impurities, and may contain a substance derived from the first raw material, the second raw material and/or the protic solvent. For example, when the quaternary ammonium salt is used as the second raw material, N may be present (remain) in an arbitrary form in the material containing MQO such as MQO nanofibers. Although the present embodiment is not limited, the material containing MQO may contain ammonium ions and tetramethylammonium ions. For example, when the MAX raw material is used as the first raw material, in the present disclosure, the material containing MQO may contain a relatively small amount of remaining A atoms, for example, 10% by mass or less with respect to the original A atoms. The remaining amount of A atoms can be preferably 8% by mass or less, and more preferably 6% by mass or less. However, even if the remaining amount of A atoms exceeds 10% by mass, there may be no problem depending on the use conditions or the like.

[0064] In order to obtain the material containing MQO such as MQO nanofibers with higher purity, it is preferable to repeat washing and centrifugation multiple times and to recover the supernatant liquid after final centrifugation. Such a supernatant liquid can be formed into a slurry containing MQO particles such as MQO nanofibers as it is, appropriately diluted with a liquid medium, or mixed with a liquid medium after drying.

[0065] The wick of the present embodiment can be produced by shaping (molding or cutting or the like) a material containing MQO such as MQO nanofibers into a desired shape and dimension by any appropriate method. Typically, the wick of the present embodiment may be a fiber structure formed using MQO nanofibers or the like. Such a fiber structure may be produced, for example, by applying a slurry containing MQO nanofibers onto a substrate by any suitable method (for example, filtering, spraying, bar coating, spin coating, and immersing and the like), drying, and then removing the substrate. The liquid medium contained in the slurry can be appropriately selected, and for example, a protic solvent (the same description as described above can be applied), an aprotic solvent (for example, tetrahydrofuran, methylene chloride, acetonitrile, acetone, N,N-dimethylformamide, and dimethylsulfoxide and the like), a non-polar solvent (for example, hexane, benzene, toluene, diethyl ether, chloroform, and ethyl acetate) and the like can be used.

[0066] As described above, the wick of the present embodiment is obtained. The shape and dimension of the wick of the present embodiment can be appropriately selected according to a desired application.

[0067] As described above, the material containing MQO may typically have a peak in a range in which a diffraction angle 2θ is not less than 2° and not more than 100° in an X-ray diffraction (XRD) pattern. Although the present disclosure is not bound by any theory, the fact that the material containing MQO has a peak in a range of 2θ =not less than 2° and not more than 100° in the XRD pattern is considered

to mean that MQO has a crystal structure different from that of a well-known metal oxide.

[0068] In the present disclosure, an XRD pattern is a pattern (the vertical axis represents intensity, and the horizontal axis represents 2θ) obtained by θ -axis direction scanning with an XRD analyzer using $\text{CuK}\alpha$ rays (=about 1.54 Å) as characteristic X-rays, and may also be referred to as an "XRD profile". The peaks in the XRD pattern can be identified visually or using a software used with the XRD analyzer. In order to measure an XRD pattern in a low angle range of 2θ as accurately as possible, it is preferable to install a c-axis oriented MQO membrane in an XRD analyzer (for example, as in Examples described later, a self-standing membrane obtained by removing a filter after suction filtration is disposed with a surface in contact with the filter on a lower side) to perform the measurement.

[0069] Although the present embodiment is not limited, for example, the material of the present embodiment (more specifically, MQO) may have a Raman shift with peaks at positions of at least 275 to 295 cm^{-1} , 435 to 455 cm^{-1} , and 665 to 745 cm^{-1} in a Raman spectrum using a laser with a wavelength of 514 nm.

[0070] Although the present embodiment is not limited, for example, the material of the present embodiment (more specifically, MQO) may have a Raman shift with peaks at positions of 140 to 160 cm^{-1} , 275 to 295 cm^{-1} , 435 to 455 cm^{-1} , and 665 to 745 cm^{-1} in a Raman spectrum using a laser with a wavelength of 514 nm. Incidentally, at the position of 140 to 160 cm^{-1} , an anatase type peak is present.

[0071] Although the present embodiment is not limited, for example, the material of the present embodiment (more specifically, MQO) has a crystal structure of an anatase type, a lepidocrocite type, or a mixture thereof. More preferably, the material has a lepidocrocite type crystal structure.

[0072] Although the present embodiment is not limited, for example, the material of the present embodiment (more specifically, MQO) may have an aspect in which a Raman shift has peaks at positions of at least 275 to 295 cm^{-1} , 435 to 455 cm^{-1} , and 665 to 745 cm^{-1} in a Raman spectrum using a laser with a wavelength of 514 nm, and X is the largest when the intensity of each of the peaks is X, Y, and Z.

[0073] Although the present embodiment is not limited, more preferably, the material of the present embodiment (more specifically, MQO) may have an aspect in which in a Raman spectrum using a laser with a wavelength of 514 nm, a Raman shift has peaks at positions of at least 180 to 200 cm^{-1} , 275 to 295 cm^{-1} , 375 to 395 cm^{-1} , 435 to 455 cm^{-1} , and 665 to 745 cm^{-1} , and X is the largest when the intensity of each of the peaks is V, X, Y, Z, and W.

[0074] In the present disclosure, the Raman spectrum is measured by a Raman spectrometer using a laser beam having a wavelength of 514 nm as an excitation light source (the vertical axis represents intensity, and the horizontal axis represents a Raman shift). The peaks in the Raman spectrum can be identified visually or using a software used with the Raman spectrometer.

[0075] The particle diameter of the MQO particles may be, for example, 0.01 nm or more, particularly 0.1 nm or more, and 1 nm or more, and/or may be, for example, less than 1000 nm, particularly 100 nm or less, and 50 nm or less. Such particles may also be referred to as nanoparticles.

[0076] The form of the MQO particles is a nanofiber and/or a two-dimensional substance. The two-dimensional

substance includes one or more of nanoflake and a laminate of nanoflake. In the present embodiment, the two-dimensional substance is not limited to only the nanoflake and the laminate of nanoflake.

[0077] According to the present embodiment, there is provided a wick containing a material containing MQO, typically MQO particles (for example, nanofibers/nanoflakes), for example, MQO nanofibers (and optionally an assembly of MQO nanofibers, for example MQO nanoflakes). For example, the MQO nanofibers have a hydrophilic surface and have a cross-sectional outer dimension on the order of nanometers. The wick containing the MQO nanofibers has a large force (for example, a sucking force) for sucking the working fluid in the liquid state by capillary action, and thus can transfer (for example, suck) the working fluid in the liquid state at a large speed. It is considered that the reason is that the volume density of the nanofibers in the wick is high due to the nano-order cross-sectional outer dimension, a narrow space (flow path of the working fluid) is formed by the gap of the nanofibers, and the total surface area of the nanofibers that can be in contact with the working fluid in the liquid state increases, and the hydrophilic surface makes the working fluid in the liquid state (typically, but not limited to, water) easily wet spread with respect to the surface of the nanofibers of MQO.

[0078] In the present disclosure, the “nanofiber” of MQO means a solid object extending in a longitudinal direction, and an outer dimension (cross-sectional outer dimension) of a cross section perpendicular to the longitudinal direction is on the nano order (that is, not less than 1 nm and less than 1000 nm) or on the sub-nano order smaller than the nano order (less than 1 nm, for example, not less than 0.1 nm and less than 1 nm). The longitudinal length of the nanofiber of MQO is not particularly limited. That is, the longitudinal length of the nanofiber is not limited to the nano order (that is, not less than 1 nm and less than 1000 nm), and may be in the micron order (not less than 1 μm and less than 1000 μm). The cross-sectional outer dimension of the nanofiber may be, for example, 0.1 nm or more, and particularly 1 nm or more, and may be, for example, 100 nm or less, particularly 50 nm or less, and preferably 15 nm or less. The wick containing the MQO nanofibers and the like having such small cross-sectional outer dimensions can transfer the working fluid in the liquid state at a higher speed. Although the present embodiment is not limited, according to the above-described producing method, it is possible to realize the MQO nanofibers having such small cross-sectional outer dimensions.

[0079] In the present disclosure, the cross-sectional outer dimension of the MQO nanofibers means the shortest distance passing through the center in the cross section crossing the longitudinal direction of the MQO nanofibers. The shape of the cross section of the MQO nanofibers is not particularly limited, but can be approximated by, for example, a rectangle (rectangle and square and the like) or an ellipse (flat circle and true circle and the like). When the MQO nanofibers are in the form of nanoribbons, the shape of the cross-section thereof can be approximated by the rectangle, and the cross-sectional outer dimension can correspond to the short side length of the rectangle. When the MQO nanofibers are in the form of nanofilaments, the shape of the cross section thereof can be approximated by the flat circle, and the cross-sectional outer dimension can correspond to the short diameter length of the flat circle.

[0080] The BET specific surface area of the material containing MQO such as MQO nanofibers is not particularly limited, and may be, for example, not less than 10 m^2/g and not more than 500 m^2/g . The BET specific surface area is calculated using a BET equation from the isothermal adsorption curve of nitrogen gas or other gases at a liquid nitrogen temperature (77 K) by an adsorption method with the nitrogen gas or the other suitable gases (such as krypton (Kr) gas).

[0081] In the present disclosure, a “two-dimensional substance” means a solid having a two-dimensionally extending surface (also referred to as a plane or a two-dimensional sheet surface) and having a thickness relatively small with respect to a maximum dimension of the surface (which may correspond to the “in-plane dimension” of a particle), the thickness being on the order of nanometers (that is, not less than 1 nm and less than 1000 nm) or sub-nanometers (less than 1 nm, for example, not less than 0.1 nm and less than 1 nm) smaller than that. The in-plane dimension is not limited to the nano order (that is, not less than 1 nm and less than 1000 nm), and may be the micron order (not less than 1 μm and less than 1000 μm). The two-dimensional substance includes one or more of nanoflake and a laminate of nanoflake as described above. The nanoflake may also be referred to as a nanosheet or a two-dimensional (nano) sheet. The thickness of one layer of the nanoflake may be, for example, 0.01 nm or more, particularly 0.8 nm or more and, for example, 20 nm or less, particularly 3 nm or less. The in-plane dimension of the nanoflake may be, for example, 0.1 μm or more, particularly 1 μm or more, and may be, for example, 200 μm or less, particularly 40 μm or less. The nanoflake can be constituted by the aggregation of nanofibers.

[0082] The stack of the nanoflakes may also be referred to as a multilayer MQO. A distance (interlayer distance or void dimension) between two adjacent nanoflakes (or MQO of two adjacent layers) is not particularly limited.

[0083] Each dimension described above can be obtained as a number average dimension (number average of at least 40) based on a photograph observed with a scanning electron microscope (SEM), a transmission electron microscope (TEM), or an atomic force microscope (AFM) (if necessary, processing is performed by a method such as a focused ion beam (FIB)), or a distance in a real space calculated from a position on a reciprocal lattice space of a (002) plane measured by an X-ray diffraction (XRD) method. In the present disclosure, for example, the cross-sectional outer dimensions of the MQO nanofibers are obtained by exposing the cross section of the wick containing the MQO nanofibers by a method such as a focused ion beam (FIB), photographing the exposed cross section with a scanning electron microscope (SEM) or a transmission electron microscope (TEM), extracting at least 40 samples in which a cross section crossing the longitudinal direction of the MQO nanofibers appears in the obtained image, and calculating the number average of the cross-sectional outer dimensions.

[0084] However, it should be noted that in the present disclosure, MQO is not limited to the above-described form, and may have any suitable form.

Second Embodiment: Heat Transport Device

[0085] The present embodiment relates to a heat transport device. In the present disclosure, the “heat transport device” means a device that transports heat utilizing a phase change

of a working fluid. The phase change of the working fluid means evaporation and condensation.

[0086] Referring to FIG. 1, a heat transport device 20 of the present embodiment includes: a housing 1 having a space therein; a wick 3 disposed in the housing 1; and a working fluid (not shown) sealed in the housing 1 in a state of being able to contact the wick 3. The wick 3 described above in the first embodiment is used.

[0087] Although the present embodiment is not limited, FIG. 1 exemplarily shows a case where the heat transport device 20 is a loop heat pipe. In the illustrated example, the housing 1 includes an evaporator 11, a condenser 13, and a gas flow path 15 and a liquid flow path 17 connecting the evaporator and the condenser. The evaporator 11, the condenser 13, the gas flow path 15, and the liquid flow path 17 integrally constitute the internal space of the housing 1. The wick 3 is disposed in the evaporator 11. A working fluid (not shown) is sealed in the internal space of the housing 1. The housing 1 is made of a material (for example, metal) having thermal conductivity at least in the evaporator 11 and the condenser 13.

[0088] In the housing 1, the working fluid evaporates in the evaporator 11 (relatively high temperature portion) to which heat is supplied from the outside (heat source), the working fluid in the gaseous state moves in the gas flow path 15 and condenses in the condenser 13 (relatively low temperature portion) to release heat to the outside, and the working fluid in the liquid state is transferred (returned) to the evaporator 11 through the liquid flow path 17 by the capillary force of the wick 3. As a result, the working fluid circulates in the housing 1 while changing in phase. In FIG. 1, the flow of the working fluid is schematically shown by dotted arrows, and the supply of heat from the outside (heat input) and heat dissipation to the outside (heat output) are schematically shown by wavy arrows.

[0089] According to the present embodiment, since the wick 3 described above in the first embodiment is used in the heat transport device 20, the working fluid in the liquid state can be transferred at a high speed, high heat transport performance is obtained, and the maximum heat transport amount of the heat transport device 20 is improved.

[0090] In the example shown in FIG. 1, the case where the heat transport device 20 is the loop heat pipe has been described. However, the heat transport device of the present embodiment may employ the configuration of a known heat transport device (for example, a tubular heat pipe or a vapor chamber or the like) including a wick except that the wick 3 described above is used in the first embodiment.

[0091] Although the wick and the heat transport device in an embodiment of the present disclosure have been described in detail above, the present disclosure can be modified in various ways. It should be noted that the wick of the present disclosure may be produced by a method different from the producing method in the above-described embodiment.

EXAMPLES

Example 1

[0092] Example 1 relates to a wick of a first embodiment using TiCO nanofibers.

[0093] Preparation of Slurry Containing TiCO Nanofibers

[0094] First, a container (100 mL I Boy) was charged with 1 g of titanium diboride (TiB_2 , manufactured by Alfa Aesar) and 30 mL of a 25 mass % aqueous tetramethylammonium hydroxide (TMAH) solution (manufactured by Tokyo Chemical Industry Co., Ltd.). Thereto was placed a stirrer chip having a length substantially equal to the inner diameter of the circular bottom surface of the container (35 mm). While the container was kept at 50° C. in a water bath, the mixture in the container was stirred with the stirrer chip and maintained for 120 hours, thereby allowing the reaction to proceed. Next, the reaction mixture in the container was transferred to a 50 mL centrifuge tube with a stainless steel spatula (without the addition of a liquid medium such as ethanol or water). Centrifugation was performed using a centrifuge under conditions of 3500 G and 5 minutes to precipitate the solid content. (i) After centrifugation, the supernatant liquid was discarded, (ii) 40 mL of ethanol (manufactured by FUJIFILM Wako Pure Chemical Corporation) was added to the remaining precipitate in the centrifuge tube, and the mixture was subjected to handshake for 5 minutes (reslurry), and (iii) centrifugation was performed under the same conditions as described above. The operations (i) to (iii) were repeated until the pH of the supernatant liquid was 8 or less. When the operations were repeated three times, the pH of the supernatant liquid became 8 or less. Therefore, this supernatant liquid was discarded, and the repeated operations were terminated. 40 mL of pure water was added to the remaining precipitate in the centrifuge tube, and the mixture was shaken and stirred for 15 minutes using an automatic shaker. Thereafter, centrifugation was performed using a centrifuge under the conditions of 3500 G and 30 minutes, and the supernatant liquid was recovered as a sample slurry. The obtained sample slurry corresponds to a slurry containing TiCO nanofibers (see the following analysis results).

[0095] Preparation of Wick

[0096] The sample slurry prepared above was filtered with suction overnight using a nutsche. As a filter for suction filtration, a membrane filter (Durapore, pore diameter 0.45 μm , manufactured by Merck Corporation) was used. After suction filtration, a precursor membrane on the filter was dried overnight at 80° C. in a vacuum oven, and the filter was removed to obtain a free-standing membrane. The obtained free-standing membrane was cut into a rectangle to obtain a wick sample having a width (W) of 1 cm, a length (L) of 2 cm, and a thickness (T) of 100 μm .

[0097] Evaluation of Wick

[0098] The wick sample prepared above was placed on a petri dish containing water in a state of being vertically erected so that a WT surface (1 cm $\times$ 100 μm) was an upper end surface and a lower end surface, and immersed in water at a depth of about 1 mm. Water was sucked up to the upper end surface at a speed of 4 mm/s. From this result, the volume of water sucked up by the wick sample per unit time unit area is $4 \times 10^{-3} \text{ m}^3/(\text{m}^2 \cdot \text{s})$, and thus the mass of water sucked up per unit time unit area is 4 kg/(m $^2 \cdot$ s) (specific gravity of water: 1000 kg/m ^{3}). Since the heat of evaporation of water per unit mass at 25° C. is 2442 kJ/kg, the amount of heat that this wick sample can deprive by the evaporation of water at 25° C. is calculated to be 9768 kW/m ^{2} . That is, in the wick sample of Example 1, the transfer speed of water was 4 mm/s, and the heat transport performance of water at 25° C. was about 10 ^{4} kW/m ^{2} .

[0099] Analysis

[0100] The free-standing membrane obtained in the same manner as described above was analyzed by X-ray photoelectron spectroscopy (XPS). Peaks corresponding to Ti2p, Cl1s, O1s, and N1s were observed in the obtained XPS spectrum, and thus Ti, C, O, and N were detected. Since N is considered to be the residual content of TMAH of the raw material, the material of the free-standing membrane is considered to be composed of Ti, C, and O.

[0101] For the free-standing membrane obtained in the same manner as described above, an XRD profile was measured using an XRD apparatus (MiniFlex manufactured by Rigaku Corporation) (characteristic X-ray: $\text{CuK}\alpha=1.54 \text{ \AA}$). The obtained XRD pattern is shown in FIG. 2. As understood from FIG. 2, the material had a peak at $2\theta=7.26^\circ$.

[0102] 0.01 g of a slurry containing TiCO nanofibers obtained in the same manner as described above and 1 g of pure water were added to the centrifuge tube, followed by shaking and stirring for 5 minutes using an automatic shaker. The obtained slurry was added dropwise to an alumina porous substrate (manufactured by Cytiva), and the TiCO nanofibers were observed using FE-SEM (S-4800, manufactured by Hitachi High-Tech Co., Ltd.). FIG. 3 shows an FE-SEM image. As understood from FIG. 3, the material had a cross-sectional outside dimension of about 5 nm.

Comparative Example 1

[0103] Comparative Example 1 relates to a wick using MXene particles as one type of two-dimensional material.

[0104] Preparation of MAX particles (precursor of MXene particles)

[0105] TiC powder, Ti powder, and Al powder (all manufactured by Kojundo Chemical Laboratory Co., Ltd.) were placed in a ball mill containing zirconia balls at a molar ratio of 2:1:1 and mixed for 24 hours. The obtained mixed powder was calcined in an Ar atmosphere at 1350°C . for 2 hours. The fired body (block) thus obtained was crushed with an end mill to a maximum size of $40 \mu\text{m}$ or less. Thereby, Ti_3AlC_2 particles were obtained as MAX powder.

[0106] Etching of Precursor (ACID Method)

[0107] Using the Ti_3AlC_2 particles (powder) prepared by the above method, etching was performed under the following etching conditions to obtain a solid-liquid mixture (slurry) containing a solid component derived from the Ti_3AlC_2 powder.

(Etching Conditions)

- [0108] Precursor: Ti_3AlC_2 (Sieving with aperture of $45 \mu\text{m}$)
- [0109] Etching solution composition: 49% HF 6 mL
- [0110] H_2O 18 mL
- [0111] HCl (12M) 36 mL
- [0112] Amount of precursor charged: 3.0 g
- [0113] Etching container: 100 mL I Boy
- [0114] Etching temperature: 35°C .
- [0115] Etching time: 24 h
- [0116] Stirrer rotation speed: 400 rpm
- [0117] Washing after etching

[0118] The slurry was divided into two portions, each of which was inserted into two 50 mL centrifuge tubes, centrifuged under the condition of 3500 G using a centrifuge. Then, the supernatant liquid was discarded. An operation of adding 40 mL of pure water to the remaining precipitate in each centrifuge tube, centrifuging again at 3500 G, and

separating and removing the supernatant liquid was repeated 11 times. After final centrifugation, the supernatant liquid was discarded to obtain a $\text{Ti}_3\text{C}_2\text{T}_x$ -moisture medium clay.

[0119] Li intercalation

[0120] The $\text{Ti}_3\text{C}_2\text{T}_x$ -moisture medium clay prepared by the above method was stirred at not lower than 20°C . and not higher than 25°C . for 12 hours using LiCl as a Li-containing compound to perform Li intercalation according to the following conditions.

(Conditions of Li Intercalation)

- [0121] $\text{Ti}_3\text{C}_2\text{T}_x$ -moisture medium clay (MXene after washing): Solid content 0.75 g
- [0122] LiCl: 0.75 g
- [0123] Intercalation container: 100 mL I Boy
- [0124] Temperature: not lower than 20°C . and not higher than 25°C . (room temperature)
- [0125] Time: 10 h
- [0126] Stirrer rotation speed: 800 rpm
- [0127] Delamination

[0128] (i) 40 mL of pure water was added to the $\text{Ti}_3\text{C}_2\text{T}_x$ -moisture medium clay, followed by stirring with a shaker for 15 minutes; (ii) the mixture was centrifuged at 3500 G; and (iii) the supernatant liquid was recovered as a single-layer MXene-containing liquid. The operations (i) to (iii) were repeated four times in total to obtain a single-layer MXene-containing supernatant liquid. Furthermore, this supernatant liquid was centrifuged under the conditions of 4300 G and 2 hours using a centrifuge, and then the supernatant liquid was discarded to obtain a single-layer/few-layer MXene-containing clay as a single-layer/few-layer MXene-containing sample.

[0129] Preparation of Slurry Containing MXene Particles

[0130] The MXene-containing clay and pure water were mixed in appropriate amounts to prepare a sample slurry having a solid content concentration (MXene particle concentration) of 34 mg/mL. The obtained sample slurry corresponds to a slurry containing MXene particles (MXene-water dispersion).

[0131] Preparation of Wick

[0132] A wick sample having a width (W) of 1 cm, a length (L) of 2 cm, and a thickness (T) of $100 \mu\text{m}$ was obtained in the same manner as in Example 1 except that the sample slurry prepared above was used.

[0133] Evaluation of Wick

[0134] When the wick sample prepared above was placed on a petri dish containing water in a state of being vertically erected so that a WT surface ($1 \text{ cm} \times 100 \mu\text{m}$) was an upper end surface and a lower end surface, and immersed in water at a depth of about 1 mm, water could not be sucked up at all (sucking height: 0 mm).

Comparative Example 2

[0135] Comparative Example 2 relates to a wick using a sintered body (porous metal sintered body) of metal powder (copper powder).

[0136] Preparation of Wick

[0137] Copper powder having an average particle diameter D50 of $50 \mu\text{m}$ was used as metal powder, and an acrylic resin (binder) and the copper powder were mixed at a volume ratio of 1:1. The obtained mixture was subjected to a heat treatment at 400°C . for 1 hour to burn and remove the

acrylic resin, thereby obtaining a porous metal sintered body. The obtained porous metal sintered body was cut to obtain a wick sample having a width (W) of 1 cm, a length (L) of 2 cm, and a thickness (T) of 100 μm .

[0138] Evaluation of Wick

[0139] The wick sample prepared above was placed on a petri dish containing water in a state of being vertically erected so that a WT surface (1 cm $\times$ 100 m) was an upper end surface and a lower end surface, and immersed in water at a depth of about 1 mm. Water was sucked up to the upper end surface at a speed of 0.5 mm/s. From this result, in the wick sample of Comparative Example 2, the transfer speed of water was 0.5 mm/s, and the heat transport performance of water at 25° C. was about 10³ kW/m² by the same calculation as in Example 1.

Comparative Example 3

[0140] Comparative Example 3 relates to a wick using a sintered body (porous metal sintered body) of metal powder (titanium powder).

[0141] Preparation of Wick

[0142] A wick sample having a width (W) of 1 cm, a length (L) of 2 cm, and a thickness (T) of 100 μm was obtained in the same manner as in Comparative Example 2 except that titanium powder having an average particle diameter D50 of 50 μm was used as the metal powder.

[0143] Evaluation of Wick

[0144] The wick sample prepared above was evaluated in the same manner as in Comparative Example 2, and water was sucked up to the upper end surface at a speed of 0.5 mm/s. From this result, in the wick sample of Comparative Example 3, the transfer speed of water was 0.5 mm/s, and the heat transport performance of water at 25° C. was about 10³ kW/m².

[0145] The wick of the present disclosure can be used to transfer a working fluid by capillary force in a heat transport device utilizing the phase change of the working fluid. The heat transport device of the present disclosure may be incorporated into an electronic device and used to release (remove) heat from a heat source of the electronic device. However, the wick and heat transport device of the present disclosure can be utilized for any suitable application, not only these.

[0146] $\langle 1 \rangle$ A wick used for heat transport, the wick comprising a nanofiber as a material represented by the following formula:



[0147] wherein

[0148] M is at least one element selected from the group consisting of Groups 3, 4, 5, 6, or 7,

[0149] Q is at least one element (excluding O) selected from the group consisting of Groups 12, 13, 14, 15, or 16,

[0150] a is not less than 0 and not more than 2, and

[0151] b is more than 0 but not more than 2 or less.

[0152] $\langle 2 \rangle$ The wick according to $\langle 1 \rangle$, wherein the material of the nanofiber has a peak in a range in which a diffraction angle 2θ is not less than 2° and not more than 10° in an X-ray diffraction pattern.

[0153] $\langle 3 \rangle$ The wick according to any of $\langle 1 \rangle$ or $\langle 2 \rangle$, wherein the nanofiber has a cross-sectional outer dimension of not less than 1 nm and not more than 15 nm or less.

[0154] $\langle 4 \rangle$ A heat transport device utilizing a phase change of a working fluid, the heat transport device comprising: a housing having a space therein; the wick according to any one of $\langle 1 \rangle$ to $\langle 3 \rangle$, disposed in the housing; and the working fluid sealed in the housing in a contactable state with the wick.

REFERENCE SIGNS LIST

[0155] 1 housing

[0156] 3 wick

[0157] 11 evaporator

[0158] 13 condenser

[0159] 15 gas flow path

[0160] 17 liquid flow path

[0161] 20 heat transport device

1. A wick comprising:

a material containing a nanofiber and/or a two-dimensional substance represented by:



wherein

M is at least one element selected from Groups 3, 4, 5, 6, or 7,

Q is at least one element selected from Groups 12, 13, 14, 15, or 16, excluding O,

a is more than 0 but not more than 2, and

b is more than 0 but not more than 2.

2. The wick according to claim 1, wherein M is at least one element selected from Ti, V, Cr, Mo and Mn.

3. The wick according to claim 1, wherein Q is at least one element selected from B, C, N, Si, P, and S.

4. The wick according to claim 1, wherein the material containing the nanofiber and/or the two-dimensional substance has a peak in a range in which a diffraction angle 2θ is not less than 2° and not more than 10° in an X-ray diffraction pattern.

5. The wick according to claim 1, wherein the material containing the nanofiber and/or the two-dimensional substance has a Raman shift with peaks at positions of 275 to 295 cm^{-1} , 435 to 455 cm^{-1} and 665 to 745 cm^{-1} in a Raman spectrum with a laser at a wavelength of 514 nm.

6. The wick according to claim 1, wherein the material containing the nanofiber and/or the two-dimensional substance has a Raman shift with peaks at positions of 140 to 160 cm^{-1} , 275 to 295 cm^{-1} , 435 to 455 cm^{-1} and 665 to 745 cm^{-1} in a Raman spectrum with a laser at a wavelength of 514 nm.

7. The wick according to claim 6, wherein an anatase type peak is present at a position of 140 to 160 cm^{-1} .

8. The wick according to claim 1, wherein the material containing the nanofiber and/or the two-dimensional substance has a crystal structure of an anatase, a lepidocrocite, or a mixture thereof.

9. The wick according to claim 1, wherein the material containing the nanofiber and/or the two-dimensional substance has a lepidocrocite crystal structure.

10. The wick according to claim 1, wherein

the material containing the nanofiber and/or the two-dimensional substance has a Raman shift with peaks at positions of at least 180 to 200 cm^{-1} , 275 to 295 cm^{-1} , 375 to 395 cm^{-1} , 435 to 455 cm^{-1} , and 665 to 745 cm^{-1} in a Raman spectrum with a laser having a wavelength of 514 nm, and

X is largest when an intensity of each of the peaks is V, X, Y, Z, and W.

11. The wick according to claim **1**, wherein the nanofiber has a cross-sectional outer dimension of not less than 1 nm and not more than 15 nm.

12. The wick according to claim **1**, wherein the wick is made of the material substantially consisting of the nanofiber and/or the two-dimensional substance.

13. A heat transport device comprising:

a housing having a space therein;

the wick according to claim **1** in the space of the housing;

and

a working fluid in space of the housing in a contactable state with the wick.

14. The heat transport device according to claim **13**, wherein the material containing the nanofiber and/or the two-dimensional substance has a peak in a range in which a diffraction angle 2θ is not less than 2° and not more than 10° in an X-ray diffraction pattern.

15. The heat transport device according to claim **13**, wherein the material containing the nanofiber and/or the two-dimensional substance has a Raman shift with peaks at positions of 275 to 295 cm^{-1} , 435 to 455 cm^{-1} and 665 to 745 cm^{-1} in a Raman spectrum with a laser at a wavelength of 514 nm .

16. The heat transport device according to claim **13**, wherein the material containing the nanofiber and/or the

two-dimensional substance has a Raman shift with peaks at positions of 140 to 160 cm^{-1} , 275 to 295 cm^{-1} , 435 to 455 cm^{-1} and 665 to 745 cm^{-1} in a Raman spectrum with a laser at a wavelength of 514 nm .

17. The heat transport device according to claim **13**, wherein the material containing the nanofiber and/or the two-dimensional substance has a crystal structure of an anatase, a lepidocrocite, or a mixture thereof.

18. The heat transport device according to claim **13**, wherein the material containing the nanofiber and/or the two-dimensional substance has a lepidocrocite crystal structure.

19. The heat transport device according to claim **13**, wherein

the material containing the nanofiber and/or the two-dimensional substance has a Raman shift with peaks at positions of at least 180 to 200 cm^{-1} , 275 to 295 cm^{-1} , 375 to 395 cm^{-1} , 435 to 455 cm^{-1} , and 665 to 745 cm^{-1} in a Raman spectrum with a laser having a wavelength of 514 nm , and

X is largest when an intensity of each of the peaks is V, X, Y, Z, and W.

20. The heat transport device according to claim **13**, wherein the nanofiber has a cross-sectional outer dimension of not less than 1 nm and not more than 15 nm.

* * * * *