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(54) Title: HEAT PIPE FOR ELECTRONIC DEVICE, AND METHOD OF MANUFACTURING THEREFOR

(57) **Abstract:** Disclosed is a heat pipe (100) for an electronic device. The heat pipe (100) comprises a body (102) having a generally planar, metallic structure. The body comprises a first module (102A) and a second module (102B) joined together to define an internal volume. Each of the first module (102A) and the second module (102B) has a foldable portion (106) therein. The heat pipe further comprises a polymeric layer (104) disposed over the foldable portion (106) of each of the first module (102A) and the second module (102B), of the body (102).

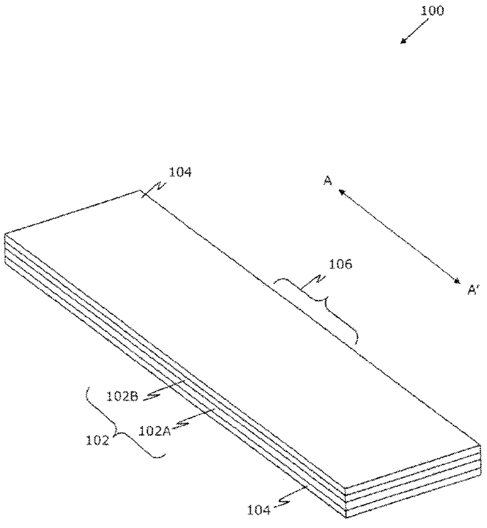

FIG. 1A

WO 2021/232134 A1

HEAT PIPE FOR ELECTRONIC DEVICE, AND METHOD OF MANUFACTURING THEREFOR

TECHNICAL FIELD

[0001] The present disclosure relates generally to electronic devices; and more specifically, to a heat pipe and a method for manufacturing a heat pipe for use in electronic devices.

BACKGROUND

[0002] With the rapid development in electronic device technologies, the demand for cooling systems capable of dissipating heat at high efficiency for electronic devices is increased. To counter or dissipate the heat generated, an electronic device may include a heat dissipating device, such as a heat pipe. The purpose of a heat pipe is to move the heat from the point of generation to a remote location for dissipation. A heat pipe is a sealed, usually evacuated chamber which contains a liquid coolant. The liquid coolant or working fluid changes phase as it absorbs and dissipates heat. The coolant changes from liquid to vapour as heat is transferred to it from heat source in the electronic device, and changes from vapour back to liquid as it dissipates the heat to the surrounding environment.

[0003] Depending on overall shape and architecture of internal space in the electronic device, heat pipes can operate according to some basic principles or its combinations. For instance, traditional heat pipes have mostly one-dimensional transport of heat, liquid recirculate through the porous body due to acting of capillary forces; vapour chambers based heat pipes mostly have two-dimensional transport of heat, with liquid recirculating through the porous body due to acting of capillary forces; thermo-syphon or loop thermo-syphon based heat pipes have liquid recirculate through the channels due to acting of gravity forces; loop heat pipe have liquid recirculate through the channels due to acting of capillary forces; pulsating heat pipe have liquid recirculate (oscillate) in the loop of channels due to acting of capillary forces, expansion of internal fluid during evaporation and collapsing of internal fluid during condensation.

[0004] Currently, metallic heat pipes are employed as standard technology which suits for mass production with high quality and performance. But rapid developments of new kinds of electronic devices, generate more challenging requirements for heat pipes. One of the challenging area of application of heat pipes are flexible and foldable products like foldable smartphones or laptops, which have at least two foldable parts with hinged connection between each other, where heat should be transferred from one to another part. Since conventional heat pipes are relatively rigid because those are made out of rigid materials, such as copper tubes or pieces of sheet metal, their implementation for heat transfer between foldable parts may not be possible due to damage to rigid case after several times of folding. Some heat pipes may include tubular expandable bellows to permit bending of the heat pipe when it is installed in an electronic device so as to be bent into their final fixed shape, but those conventional heat pipes cannot be readily and repeatably deformed, either elastically or plastically.

[0005] Some research has been performed in recent years for developments of heat pipes with polymeric flexible case, but such polymer or polymer-based heat pipes have some disadvantages. Since, polymers are permeable for gases and liquids, especially for gases or liquids with small size of molecules like Water, Oxygen, Nitrogen, and Helium etc., it may lead to internal fluid (for example water) permeating (leaking) to the atmosphere due to solution-diffusion process through the polymeric wall of heat pipe and thereby decreasing amount of internal fluid over time which may not be enough for proper circulation and heat dissipation; as well as atmospheric gases like Oxygen and Nitrogen permeating from atmosphere to internal space of heat space due to solution-diffusion process through the polymeric wall, and such permeation of gases from atmosphere leading to interruption of operation of heat pipe because such gases cannot easily undergo evaporation/condensation and may occupy large areas of internal space of heat pipe which disrupts proper circulation of internal liquid.

[0006] Therefore, in light of the foregoing discussion, there exists a need to overcome the aforementioned drawbacks associated with conventional heat pipes used in electronic devices.

SUMMARY

[0007] The present disclosure seeks to provide a heat pipe for use in electronic devices and a method of manufacturing therefor. The present disclosure seeks to provide a solution to the existing problem of inefficient and non-flexible heat pipes for the electronic devices, especially for foldable electronic devices. An aim of the present disclosure is to provide a solution that overcomes at least partially the problems encountered in prior art, and provides improved cooling system that is able to efficiently dissipate heat and provide effective cooling in electronic devices, especially in foldable electronic devices. The proposed heat pipe is designed to be suitable for mass production, and have balanced mechanical flexibility and low permeability of gases from atmosphere to internal space and vice-versa.

[0008] The object of the present disclosure is achieved by the solutions provided in the enclosed independent claims. Advantageous implementations of the present disclosure are further defined in the dependent claims.

[0009] In a first aspect, a heat pipe for an electronic device is provided. The heat pipe comprises a body having a generally planar, metallic structure. The body comprises a first module and a second module joined together to define an internal volume. Each of the first module and the second module has a foldable portion therein. The heat pipe further comprises a polymeric layer disposed over the foldable portion of each of the first module and the second module, of the body.

[0010] The present heat pipe can provide effective heat dissipation for electronic devices, especially for the foldable electronic devices. When the electronic device is folded during operation, the polymeric layer does not develop cracks due to large elongation at break property of polymers even if the metallic structure of the body may develop cracks. Hence, a working fluid in the internal volume of the heat pipe may only leak through small area of the polymeric layer where the metallic structure might have developed cracks, and since such area of the polymeric layer near cracks would generally be quite small, leakage rate of the working fluid would be much less as compared to permeation through a traditional heat pipe having only polymeric layer. Low leakage rate of the working fluid leads to inconsiderable decrease in amount of working fluid, hence the foldable heat pipe provides consistent heat dissipation in foldable electronic devices over time, and thus increases lifetime of the heat pipe.

[0011] In a first implementation form of the first aspect, the first module comprises a plurality of projections located inside the internal volume.

[0012] The plurality of projections in the first module supports the second module over the first module, creating gap between the first module and the second module for proper circulation of the working fluid in the internal volume and allows efficient heat dissipation.

[0013] In a second implementation form of the first aspect, the plurality of projections comprises a first set of projections and a second set of projections, wherein the second set of projections is arranged on the foldable portion of the first module and extend along a longitudinal direction of the body.

[0014] The first set of projections extend vertically from an inner surface of the first module, creating gap between the first module and the second module for effective circulation of the working fluid in the internal volume. The second set of projections extend vertically as well as along the longitudinal direction of the body and are formed in the foldable portion on the inner surface of the first module. The second set of projections allows bending of at least the first module around the foldable portion, and thereby reduces chances of formation of cracks such portion and in turn increases durability of the heat pipe.

[0015] In a third implementation form of the first aspect, the heat pipe comprises a porous layer having a plurality of holes complementary to the plurality of projections in the first module, such that the porous layer is arranged on the first module inside the internal volume.

[0016] The porous layer having the plurality of holes complementary to the plurality of projections in the first module allows the porous layer to be properly arranged on the first module inside the internal volume. Presence of the porous layer provides effective circulation of the working fluid inside the internal volume which helps in more effective heat dissipation in the electronic device.

[0017] In a fourth implementation form of the first aspect, the heat pipe comprises one or more grooves formed in the foldable portion of each of the first module and the second module of the body, wherein the one or more grooves extends along a lateral direction of the body.

[0018] The one or more grooves are formed on the outer surface of each of the first module and the second module in the foldable portion. The one or more grooves allows bending of the heat pipe while reducing formation of large cracks in the body of the heat pipe. Further, the one or more grooves controls the location of formation of cracks by restricting the cracks around the foldable portion in the heat pipe.

[0019] In a fifth implementation form of the first aspect, the polymeric layer covers an outer surface of each of the first module and the second module, of the body.

[0020] The first module and the second module are impermeable metallic layers that prevents leakage of the working fluid from the internal volume to the atmosphere, but make the body more susceptible to developing cracks on bending of the heat pipe. However, the polymeric layer is generally resistant to developing cracks during bending of the heat pipe due to high flexibility of polymer as compared to the body having metallic structure. Hence, the use of polymeric layer over entire outer surface of each of the first module and the second module, and not just the foldable portions thereof, provides balanced permeability and flexibility to the heat pipe.

[0021] In a sixth implementation form of the first aspect, the polymeric layer comprises a metallic layer arranged therewith.

[0022] Since the polymeric layer is generally permeable, use of the metallic layer arranged with the polymeric layer reduces permeability of the arrangement and can significantly reduce leakage of the working fluid from the internal volume through the polymeric layer having the metallic layer arranged therewith. For example, the polymeric layer with the metallic layer arranged therewith has about 20 times smaller gas permeability compared to the polymeric layer without the metallic layer. Hence, the metallic layer arranged with the polymeric layer enhances performance of the heat pipe.

[0023] In a seventh implementation form of the first aspect the metallic layer comprises one or more indentations complementary to the one or more grooves formed in the foldable portion of each of the first module and the second module, of the body.

[0024] The one or more indentations in the metallic layer reduce formation of cracks in the metallic layer on folding of the heat pipe.

[0025] In an eighth implementation form of the first aspect, the metallic layer is embedded in the polymeric layer.

[0026] The embedding of the metallic layer in the polymeric layer allows for direct use of such polymeric layer in manufacturing of the heat pipe, thus simplifying manufacturing process. More than one metallic layer may be embedded in the polymeric layer to further reduce permeability of the working fluid.

[0027] In a ninth implementation form of the first aspect, the body is fabricated by at least one of: sintering, soldering and welding process

[0028] The aforementioned fabrication processes for fabrication of the body result in ultra-thin heat pipe. The given fabrication processes further reduce porosity and enhances strength of metals used for fabrication of the body and hence, reduces the probability of formation of cracks in the body during folding of the electronic device. Thus, the aforementioned processes result in fabrication of reliable and durable heat pipe. Further, the aforementioned processes require known production methods and may be used for mass and cost-effective production of the heat pipe.

[0029] In a tenth implementation form of the first aspect, the polymeric layer is formed of: polyimides, polyethylene terephthalate, polyethylene naphthalate, ethylene vinyl alcohol, polyamide, polyvinylidene chloride, polyacrylonitrile, nylon, or a combination thereof.

[0030] The use of such compounds for the polymeric layer allows for easy bonding of the polymeric layer with the first module and the second module. Further, such compounds have low gas permeability that reduce leakage of the working fluid to the atmosphere.

[0031] In an eleventh implementation form of the first aspect, the polymeric layer is bonded to the body using at least one of: adhesive bonding, low temperature diffusion bonding, coating and selective laser welding.

[0032] Since melting point of the polymeric layer is generally much smaller as compared to that of the body having metallic structure, the aforementioned methods allow for low temperature bonding and thus prevent damage to the polymeric layer.

[0033] In a twelfth implementation form of the first aspect, the body has a thickness in a range of 50 to 500 µm, and the polymeric layer has a thickness in a range of 15 to 200 µm.

[0034] The thickness of the body in range of 50 to 500 µm and the thickness of the polymeric layer in range of 15 to 200 µm provides a good balance of high heat dissipation and low gas permeability for the heat pipe without substantially increasing size and weight of the electronic device. Further the aforementioned thickness ranges are fabricated using present production technologies and hence, does not increases cost of production of the heat pipes.

[0035] In a thirteenth implementation form of the first aspect, the metallic layer has a thickness in a range of 0.04 to 25 µm.

[0036] The thickness of the metallic layer in range of 0.04 to 25 µm provides an effective layer that reduces permeability of the working fluid in the internal volume though the polymeric layer, without substantially increasing the size and cost of the heat pipe.

[0037] In a second aspect, the present disclosure provides a method for manufacturing a heat pipe for use in electronic devices. The method comprises fabricating a body by joining together a first module and a second module to define an internal volume, with each of the first module and the second module having a foldable portion therein; and bonding a polymeric layer over the foldable portion of each of the first module and the second module, of the body.

[0038] The method for manufacturing the heat pipe of the second aspect provides cost-effective production process for the heat pipe with potentially long lifetime and is suitable for fabrication using existing mass production approaches.

[0039] In a first implementation form of the second aspect, the method comprises disposing the polymeric layer to cover an outer surface of each of the first module and the second module, of the body.

[0040] The use of polymeric layer over entire outer surface of each of the first module and the second module, and not just the foldable portions thereof, provides balanced permeability and flexibility to the heat pipe, while making the fabrication process simpler.

[0041] In a second implementation form of the second aspect, the method comprises forming one or more grooves in the foldable portion of each of the first module and the second module of the body, extending along a lateral direction of the body.

[0042] The formation of grooves reduces overall weight of the body and reduces material usage for production of the heat pipe making the manufacturing more cost-effective. The grooves further allow bending of the heat pipe while reducing formation of large cracks in the body of the heat pipe. Further, the one or more grooves controls the location of formation of cracks by restricting the cracks around the foldable portion in the heat pipe.

[0043] In a third implementation form of the second aspect, the method comprises arranging a metallic layer with the polymeric layer.

[0044] Use of the metallic layer provides form to the polymeric layer for easy bonding to the body and further significantly reduce leakage of the working fluid from the internal volume through the polymeric layer.

[0045] In a fourth implementation form of the second aspect, the method comprises forming one or more indentations in the metallic layer complementary to the one or more grooves formed in the foldable portion of each of the first module and the second module, of the body.

[0046] The formation of indentations reduces overall weight of the metallic layer and reduces material usage for production of the heat pipe, making the manufacturing more cost-effective. The one or more indentations in the metallic layer also reduce formation of cracks in the metallic layer on folding of the heat pipe.

[0047] In a third aspect, the present disclosure provides an electronic device comprising a heat pipe.

[0048] The electronic device comprising the heat pipe of the third aspect achieves better heat dissipation and thus better performance.

[0049] All steps which are performed by the various entities described in the present application as well as the functionalities described to be performed by the various entities are intended to mean that the respective entity is adapted to or configured to perform the respective steps and functionalities. Even if, in the following description of specific embodiments, a specific functionality or step to be performed by external entities is not reflected in the description of a specific detailed element of that entity which performs that specific step or functionality, it should be clear for a skilled person that these methods and functionalities can be implemented in respective hardware elements. It will be appreciated that features of the present disclosure are susceptible to being combined in various combinations without departing from the scope of the present disclosure as defined by the appended claims.

[0050] Additional aspects, advantages, features and objects of the present disclosure would be made apparent from the drawings and the detailed description of the illustrative implementations construed in conjunction with the appended claims that follow.

BRIEF DESCRIPTION OF THE DRAWINGS

[0051] The summary above, as well as the following detailed description of illustrative embodiments, is better understood when read in conjunction with the appended drawings. For the purpose of illustrating the present disclosure, exemplary constructions of the disclosure are shown in the drawings. However, the present disclosure is not limited to specific methods and instrumentalities disclosed herein. Moreover, those in the art will understand that the drawings are not to scale. Wherever possible, like elements have been indicated by identical numbers.

[0052] Embodiments of the present disclosure will now be described, by way of example only, with reference to the following diagrams wherein:

FIG. 1A is a diagrammatic illustration of a heat pipe for an electronic device, in accordance with an embodiment of the present disclosure;

FIG. 1B is a diagrammatic illustration of the heat pipe in a folded state thereof, in accordance with an embodiment of the present disclosure;

FIG. 2A is a diagrammatic illustration of a first module of the heat pipe, in accordance with an embodiment of the present disclosure;

FIG. 2B is diagrammatic illustration of the first module in a folded state thereof, in accordance with an embodiment of the present disclosure;

FIG. 3A is a diagrammatic exploded illustration of the heat pipe showing its various components, in accordance with an embodiment of the present disclosure;

FIG. 3B is a diagrammatic exploded illustration of the heat pipe showing its various components in a folded state thereof, in accordance with an embodiment of the present disclosure;

FIG. 4 is a diagrammatic sectioned illustration of the heat pipe in a folded state thereof, in accordance with an embodiment of the present disclosure;

FIG. 5 is a diagrammatic illustration of a body of the heat pipe with one or more grooves formed therein, in accordance with an embodiment of the present disclosure;

FIG. 6 is a diagrammatic sectioned illustration of the heat pipe in a folded state thereof with a metallic layer arranged therein, in accordance with an embodiment of the present disclosure;

FIGs. 7A and 7B are diagrammatic top planar illustrations of the metallic layer with indentations formed therein, in accordance with different embodiments of the present disclosure;

FIGs. 8A, 8B and 8C are diagrammatic sectioned illustrations of the polymeric layer with the metallic layer having one or more indentations arranged therewith, in accordance different embodiments of the present disclosure;

FIG. 9 is a partial diagrammatic sectioned illustration of the polymeric layer having the metallic layer with the one or more indentations, showing dimensions of various elements therein, in accordance with an embodiment of the present disclosure;

FIG. 10 is a partial diagrammatic top planar illustration of the body having the metallic layer with the one or more indentations, showing dimensions of various elements therein, in accordance with an embodiment of the present disclosure;

FIG. 11A is a diagrammatic illustration of the heat pipe in the folded state with the body having developed crack in the foldable portion, in accordance with an embodiment of the present disclosure;

FIG. 11B is an expanded illustration of the foldable portion of the heat pipe having developed crack therein, in accordance with an embodiment of the present disclosure; and

FIG. 12 is a flowchart of a method for manufacturing the heat pipe, in accordance with an embodiment of the present disclosure.

[0053] In the accompanying drawings, an underlined number is employed to represent an item over which the underlined number is positioned or an item to which the underlined number is adjacent. A non-underlined number relates to an item identified by a line linking the non-underlined number to the item. When a number is non-underlined and accompanied by an associated arrow, the non-underlined number is used to identify a general item at which the arrow is pointing.

DETAILED DESCRIPTION OF EMBODIMENTS

[0054] The following detailed description illustrates embodiments of the present disclosure and ways in which they can be implemented. Although some modes of carrying out the present disclosure have been disclosed, those skilled in the art would recognize that other embodiments for carrying out or practicing the present disclosure are also possible.

[0055] FIG. 1A is an exemplary illustration of a heat pipe **100**, in accordance with an embodiment of the present disclosure. FIG. 1B is an exemplary illustration of the heat pipe **100** in a folded state thereof, in accordance with an embodiment of the present disclosure. The heat pipe **100** of the present disclosure is implemented as part of a cooling system for an electronic device. Herein, the electronic device may be any portable electronic device, including a laptop, a mobile phone, a computer, a tablet, a camera and the like. In such portable electronic device, some heat generation components such as an arithmetic element and an integrated circuit are built in a highly dense manner, a heat spot in which a temperature increases locally occurs, and the temperature becomes a cause of limiting arithmetic operation speed, a cause of reducing durability, or the like. The heat pipe **100** as part of the cooling system for the electronic device provides means for heat releasing and cooling in the electronic device.

[0056] The heat pipe **100** includes a body **102** and a polymeric layer **104**. The body **102** is generally planar in shape. That is, the body **102** is usually a flat structure so that the heat pipe **100** is compact and does not increase size of the electronic device. For example, the shape of the body **102** may include, but is not limited to, rectangular, square, cylindrical, and the like. The body **102** has a generally metallic structure. For example, the body **102** may be fabricated from metals such as copper, titanium, aluminium and a combination thereof. The body **102** is usually fabricated using high temperature processes as the metals linearly expand at high temperature processes that results in ultra-thin heat pipe **100**. The listed fabrication process further reduce porosity and enhances strength of the metals and hence, reduces the probability of formation of cracks in the body **102** during folding of the electronic device. Additionally, the body **102** may be fabricated from materials such as steel, stainless steel and alloys.

[0057] In an embodiment, the body **102** is fabricated by at least one of: sintering, soldering and welding process. The body **102** may be fabricated using sintering (or diffusion bonding) process at temperatures from 0.3 times to 0.95 times of melting temperature of the metal used for fabrication of the body 102. For example, the body **102** is fabricated by sintering of copper at a temperature between 320 °C to 1020 °C (generally below the melting temperature of pure copper which is about 1083 °C). The body **102** may be fabricated using soldering process at temperatures from 0.95 times to 1.05 times of melting temperature of soldering material. The body **102** may be fabricated using welding process at temperatures from 0.95 times to 1.05 times of melting temperature of the metal used for fabrication of the body **102**. In an embodiment, the body **102** has a thickness in a range of 50 to 500 µm. For example, the body **102** of the heat pipe **100** has a thickness of 150 µm. Additionally, the length of the body **102** depends on the size of the electronic device. For example, the length of the body **102** is typically about 100 mm. The given dimensions, specifically aforementioned thickness range, of the body **102** is achieved using existing production methods and no advance process is required for fabrication of the body **102**, hence the present heat pipe **100** can be manufactured in a cost-effective manner.

[0058] The body **102** comprises a first module **102A** and a second module **102B** that are joined together to define an internal volume. The first module **102A** and the second module **102B** are two metallic modules that are bonded together hermetically to form the body **102**. The first module **102A** and the second module **102B** may be bonded together using sintering process. For example, the first module **102A** and the second module **102B** are bonded together using sintering at temperature between 320 °C to 1020 °C. In other examples, the first module **102A** and the second module **102B** may be bonded together using either welding or soldering. Herein, the gap formed between the first module **102A** and the second module **102B** defines the internal volume of the heat pipe **100**. The internal volume comprises a working fluid that helps in dissipation of heat generated in the electronic device by evaporation and condensation of the working fluid. The working fluid may realize different principles of operations such as loop thermo-syphon, loop heat pipe, thermo-syphon, pulsating heat pipe for dissipation of heat generated in the electronic device. The working fluid is selected according the physical properties such as very high surface tension, good thermal stability, high latent heat, high thermal conductivity, and low liquid and vapour viscosities. Further, the type of working fluid used for the heat pipe **100** depends on the operating temperature range of the electronic device. For example, helium is used as working fluid for temperature range from −271 °C to −269 °C, methanol is used as working fluid for temperature range from 10 °C to 130 °C and water is used as working fluid for temperature range from 30 °C to 200 °C. Other types of the working fluid may include, but is not limited to ammonia, acetone, ethanol, mercury and nitrogen.

[0059] Each of the first module **102A** and the second module **102B** has a foldable portion **106** therein. The foldable portion **106** is the area in the corresponding first module **102A** and the second module **102B** from where the heat pipe **100** usually bends when the electronic device is bent. It may be understood that the body **102** (including the first module **102A** and the second module **102B**) being a metallic structure may get cracked after prolonged folding and unfolding of the electronic device. The foldable portion **106** is provided on the first module **102A** and the second module **102B** to minimize cracks in the body **102** at the position where the body **102** is bent during operation. The foldable portion **106** is formed at a centre of a length along a longitudinal direction (parallel to axis **AA'**) of the heat pipe **100** on each of the first module **102A** and the second module **102B**. Optionally, the heat pipe **100** may comprise more than one foldable portion **106** on each of the first module **102A** and the second module **102B**. For example, two foldable portions may be fabricated at predetermined distances along the length in the longitudinal direction (parallel to axis **AA'**) of the heat pipe **100** on each of the first module **102A** and the second module **102B**. As shown in FIG. 1B, the heat pipe **100** is bent along the foldable portions **106** in the body **102** along with the polymeric layers **104** formed over the outer surfaces of the first module **102A** and the second module **102B**.

[0060] The polymeric layer **104** is disposed over the foldable portion **106** of each of the first module **102A** and the second module **102B**. The polymeric layer **104** of the heat pipe **100** is a flexible layer made of one or more of polymers. In an embodiment, the polymeric layer is formed of: polyimides, polyethylene terephthalate, polyethylene naphthalate, ethylene vinyl alcohol, polyamide, polyvinylidene chloride, polyacrylonitrile, nylon, or a combination thereof. The shape of the polymeric layer **104** depends on the shape of the body **102** of the heat pipe **100**. For example, the shape of the polymeric layer **104** may include, but is not limited, to rectangular, square, cylindrical and the like. Generally, the polymeric layer **104** does not develop cracks even after many times of folding of the electronic device and hence, and thus makes the heat pipe **100** durable. The polymeric layer **104** has low oxygen transmission rate that allows minimum leakage of the working fluid from the internal volume and hence, ensures effective heat dissipation of the electronic device. The oxygen transmission rate is the measurement of the amount of oxygen gas that passes through the polymeric layer **104** over a given period. Generally, the polymeric layer **104** has oxygen transmission rate below 1.0 $cc/m^2/day/bar$ to ensure effective working of the heat pipe **100**. Further, the polymeric layer **104** has elongation at break above 25%. Elongation at break is the ratio between changed length and initial length after breakage of the polymeric layer **104**. Elongation at break expresses the capability of the polymeric layer **104** to resist changes of shape without crack formation. Higher percentage of elongation at break ensures that lower possibility of formation of cracks in the polymeric layer **104**. In an embodiment, the polymeric layer **104** has a thickness in a range of 15 to 200 µm. For example, the polymeric layer **104** of the heat pipe **100** has a thickness of 70 µm. The aforementioned thickness range of the polymeric layer **104** is a using existing production methods and no advance process is required for fabrication of the polymeric layer **104**, hence the present heat pipe **100** can be manufactured in a cost-effective manner.

[0061] As discussed, the polymeric layer **104** is disposed over the foldable portions **104** in the corresponding first module **102A** and the second module **102B**, of the body **102**. It may be understood that since the foldable portion **106** is a metallic structure, it may therefore develop large cracks after the heat pipe **100** may have been folded and unfolded multiple times; and in such case, the working fluid from the internal volume may get leaked through cracks formed near the folding area, reducing the heat dissipation efficiency of the heat pipe **100**. Hence, the foldable portions **106** are covered with the polymeric layer **104** to avoid leakage of working fluid if cracks are formed in the foldable portion **106**. Optionally, in the case where any of the first module **102A** and the second module **102B** comprises more than one foldable portion **106**, each of such foldable portion **106** may be covered with the respective polymeric layer **104**.

[0062] In an embodiment, the polymeric layer **104** covers an outer surface (such as, an outer surface **103A** of the first module **102A**, as shown in FIG. 3A) of each of the first module **102A** and the second module **102B**, of the body **102**. That is, the polymeric layer **104** covers the entire outer surface (such as, the outer surface **103A**) of each of the first module **102A** and the second module **102B**, of the body **102** and not just the foldable portions **106** thereof. Optionally, the polymeric layer **104** may cover the entire body **102** of the heat pipe **100**, that is even along vertical sides the first module **102A** and the second module **102B**, of the body **102**. It may be appreciated that this is done so as to prevent leakage of the working fluid through any possible crack formed in the body **102**, even apart from any possible cracks in the foldable portions **106** of the heat pipe **100**.

[0063] In an embodiment, the polymeric layer **104** is bonded to the body **102** using at least one of: adhesive bonding, low temperature diffusion bonding, coating and selective laser welding. The polymeric layers **104** may be covered over the foldable portions **106** using adhesive bonding between the foldable portions **106** and the corresponding polymeric layers **104**. For example, adhesive tapes, like adhesive transfer tapes such 467M (0.06 mm), double coated tape 9492M (0.05 mm), adhesive transfer tape 9471LE (0.06 mm), double lined / double coated tape 93005LE (0.05 mm), adhesive transfer tape 9471LE (0.06mm), adhesive transfer tape F9460PC (0.05mm), high temperature double coated tape 9077 (0.05mm), ultra-high temperature adhesive transfer tape 9079 (0.05mm), ultra-clear double coated tape UCT-30 (0.03mm), ultra-clear double coated tape UCT-10 (0.01mm), electrically conductive adhesive transfer tape 9707 (0.05mm), electrically conductive double-sided tape 9711S-30 (0.03mm), electrically conductive double-sided tape 9711S-50 (0.05mm), XYZ-Axis electrically conductive adhesive transfer tape 9720 (0.03mm), electrically conductive double-sided non-woven tape 9750 (0.055mm) and thermal bonding film 583 (0.05mm) may be used for bonding the foldable portion **106** and the corresponding polymeric layer **104**.

[0064] Generally, the polymeric layer **104** may be covered over the foldable portion **106** using low temperature diffusion bonding between the foldable portion **106** and the polymeric layer **104**. For example, the polymeric layer **104** is bonded with the foldable portion **106** using low temperature diffusion bonding at a temperature generally below 400 °C. As may be understood, the melting point of the polymeric layer **104** is much smaller compared to the temperature used for fabrication of the body **102**, diffusion bonding between the polymeric layer **104** and the body **102** is performed at temperatures below melting point of the polymeric layer **104** to prevent damage to the polymeric layer **104**. In an example, the polymeric layer **104** may be formed over the foldable portion **106** by coating the foldable portion **106** with liquid polymer material and then drying the liquid to form the polymeric layer **104**. Such methods for forming the polymeric layer **104** by coating the foldable portion **106** with liquid polymer material may include, but are not limited to, spin coating, slit coating, dip coating and spray coating. In another example, the polymeric layer **104** may be formed over the foldable portion **106** using selective laser welding between the foldable portion **106** and the polymeric layer **104** (i.e. a polymer sheet or the like). In selective laser welding, the polymeric layer **104** (i.e. the polymer sheet) and the foldable portion **106** are exposed to laser energy with high accuracy, such that the polymeric layer **104** is joined to the foldable portion **106**.

[0065] FIG. 2A is a diagrammatic illustration of the first module **102A** of the heat pipe **100**, in accordance with an embodiment of the present disclosure. Further, FIG. 2B is a diagrammatic illustration of the first module **102A** in a folded state thereof, in accordance with an embodiment of the present disclosure. As may be seen, the first module **102A** is bent at the foldable portion 106. As shown, in an embodiment, the first module **102A** comprises a plurality of projections **202** located inside the internal volume. The plurality of projections **202** are formed on an inner surface **103B** of the first module **102A**. The plurality of projections **202** are arrays of horizontal and vertical pillars arranged in the internal volume between the first module **102A** and the second module **102B**, when assembled together to complete the body **102**. The geometrical shape of the plurality of projections **202** may include, but is not limited to cuboid, cube, spherical and conical. The plurality of projections **202** may be fabricated from metals such as copper, titanium, aluminium and a combination thereof. Alternatively, the plurality of projections **202** may be fabricated from materials such as steel, stainless steel and alloys. Optionally, the projections 202 may be made of porous material. Optionally, the plurality of projections **202** may be fabricated by at least one of: sintering, soldering and welding process. In an example, the plurality of projections **202** is fabricated by sintering of copper at a temperature between 320 °C to 1020 °C. In another example, the first module **102A** may be a solid piece and the material is removed therefrom to form the plurality of projections **202** therein. In yet another example, the plurality of projections **202** may be bonded to the first module **102A** using sintering, welding or soldering. In an example, the plurality of projections **202** may be bonded to the first module **102A** at temperature between 320 °C to 1020 °C.

[0066] In an embodiment, the plurality of projections **202** comprises a first set of projections **202A** and a second set of projections **202B**. The first set of projections **202A** are arranged on the first module **102A** apart from the foldable portion **106** therein, while the second set of projections **202B** are arranged on the foldable portion **106**. Herein, as illustrated, two of the first set of projections **202A** are arranged adjacent along two sides of the foldable portion **106** (i.e. non-folding portions) on the first module **102A**. As shown, the first set of projections **202A** is an array of vertical pillars with respect to length of the body **102** extending vertically from the first module **102A** along an axial direction (parallel to axis **CC'**), and arranged between the first module **102A** and the second module **102B** when assembled together to form the body **102**. The first set of projections **202A** are used to create gap between the first module **102A** and the second module **102B** of the body 102 to form the internal volume such that the working fluid may circulate properly in the internal volume for effective heat dissipation. Further, as shown, the second set of projections **202B** extend along the longitudinal direction (parallel to axis **AA'**) of the body **102**. The second set of projections **202B** is an array of horizontal pillars with respect to length of the body **102** extending vertically from the first module **102A** along the axial direction (parallel to axis **CC'**), and arranged between the first module **102A** and the second module **102B** when assembled together to form the body **102**. Optionally, in case the heat pipe **100** comprises more than one foldable portion, the second set of projections (such as, the second set of projections **202B**) may be arranged on all such foldable portions. In an example, the second set of projections **202B** may also be formed on the foldable portion **106** of the second module **102B** in the heat pipe **100**. The second set of projections **202B** enables easy folding of the heat pipe **100** at the foldable portion **106** and minimize formation of cracks in the body **102** at the foldable portion **106** during folding and unfolding of the electronic device.

[0067] In an embodiment, the heat pipe **100** further comprises a porous layer **204** (better shown in FIG. 3A) having a plurality of holes complementary to the plurality of projections **202** in the first module **102A** such that the porous layer **204** is arranged on the first module **102A** inside the internal volume. The porous layer **204** may be in the form of a sheet having arrays of holes therein. The geometrical shape of the porous layer **204** may depend on the shape of the body **102**. For example, the geometrical shape of the porous layer **204** may include, but is not limited to rectangular, square, cylindrical and the like. Further, the geometrical shape of the plurality of holes in the porous layer **204** are complementary to the geometrical shape of the plurality of projections **202**. That is, the plurality of holes on the porous layer **204** is such that the plurality of projections **202** fit in the plurality of holes of the porous layer **204**. In an example, the geometrical shape of the plurality of holes of the porous layer **204** may include, but is not limited to cuboid, cube, spherical and conical. As shown, the porous layer **204** comprises a first set of holes which are generally square in shape similar to the first set of projections **202A** and a second set of holes which are rectangular having major dimension extending along the longitudinal direction (parallel to axis **AA'**) similar to the second set of projections **202B**. The porous layer **204** may be fabricated from metals such as copper, titanium, aluminium and a combination thereof. Alternatively, the porous layer **204** may be fabricated from materials such as steel, stainless steel and alloys. The porous layer **204** may be fabricated by at least one of: sintering, soldering and welding process. Optionally, the porous layer **204** can be formed by deposition of particles of metallic material to the internal surface. For example, if material of the body **102** is copper, the porous layer **204** may be fabricated by sintering of copper mesh at temperatures about 320 °C to 1020 °C. The porous layer **204** is arranged on the first module **102A** such that the porous layer **204** is positioned in between the first module **102A** and the second module **102B**, when assembled together to form the body **102**. The plurality of projections **202** creates gap between the porous layer **204** and the second module **102B**, and thus enables effective circulation of the working fluid though the porous layer (in liquid state) and in empty space of the internal volume (in vapour state) during operation of the electronic device for efficient heat dissipation.

[0068] FIG. 3A is a diagrammatic exploded illustration of the heat pipe **100** showing its various components, in accordance with an embodiment of the present disclosure. As discussed, the polymeric layers **104** cover the foldable portions **106** in the first module **102A** and the second module **102A** of the body **102** of the heat pipe **100**. Optionally, as shown and discussed earlier, the polymeric layers **104** cover the entire outer surfaces of the first module **102A** and the second module **102A** (such as, the outer surface **103A** of the first module **102A**), thereby generally covering the body **102** of the heat pipe **100**. Herein, the polymeric layers **104** form the outer most layers of the heat pipe **100**. Also, as shown, the body **102** of the heat pipe **100**

comprises the porous layer **204** placed between the first module **102A** and the second module **102A**.

[0069] FIG. 3B is a diagrammatic exploded illustration of the heat pipe **100** showing its various components in a folded state thereof, in accordance with an embodiment of the present disclosure. As may be seen, the first module **102A** is fabricated with the foldable portion **106** therein. The first module **102A** further comprises the plurality of projections **202** therein. The porous layer **204** is complementary formed to be placed on the first module **102A** such that the plurality of holes in the porous layer **204** align and sit over the plurality of projections **202** in the first module **102A**. The first module **102A** is bonded with the second module **102B** with the porous layer **204** placed between the first module **102A** and the second module **102B** occupying the internal volume, and thereby completing the body **102** of the heat pipe **100**. The body **102** is covered with the polymeric layer **104** which is hermetically bonded with the body **102**.

[0070] FIG. 4 is a diagrammatic sectioned illustration of the heat pipe in a folded state thereof, in accordance with an embodiment of the present disclosure. The body **102** comprises the first module **102A** and the second module **102A**. As shown, the outer most layers of the heat pipe **100** are the polymeric layers **104** which specifically cover the foldable portions **106** of the first module **102A** and the second module **102B**, and generally cover the outer surfaces of the first module **102A** and the second module **102B** of the heat pipe **100**. The first module **102A** further comprises the plurality of projections **202**. The plurality of projections **202** create gap between the first module **102A** and the second module **102B** to define the internal volume therein.

[0071] FIG. 5 is a diagrammatic illustration of a body of the heat pipe with one or more grooves formed therein, in accordance with an embodiment of the present disclosure. The one or more grooves **502** are formed in the foldable portions **106** of the first module **102A** and the second module **102B** of the body **102**. The one or more grooves **502** extends along a lateral direction (parallel to axis **BB'**, as shown in FIG. 2A) of the body **102**. The grooves **502** are long, narrow depressions formed in the foldable portions **106** of the first module **102A** and the second module **102B** of the body **102**. The grooves **502** on the first module **102A** and the second module **102B** are formed such that the grooves **502** are located on the side of contact with the corresponding polymeric layers **104**. The grooves **502** are extending in the direction of the axis **BB'** along which the body **102** is folded during operation of the electronic device. The grooves **502** improves flexibility of the body **102** along the foldable portions **106** and avoids formation of large cracks in the body **102** that may potentially damage the heat pipe **100**. As shown, the first module **102A** comprises the grooves **502A** and the second module **102B** comprises the grooves **502B**. Herein, the one or more grooves **502A** on the first module **102A** may be parallel or staggered with respect to the one or more grooves **502B** on the second module **102B**, as discussed later in more detail.

[0072] In an example, depth of the grooves **502** (along **CC'**) ranges from 10 µm to 100 µm, width of the grooves **502** (along **AA'**) ranges from 0.5 µm to 50 µm and pitch of the grooves **502** (along **BB'**) ranges from 0.05 mm to 5 mm. In an example, the dimensions, i.e. depth, width and pitch of the grooves **502** is 50 µm, 10 µm and 2 mm respectively. The grooves **502** with such aforementioned dimensions may be fabricated using existing production technologies, and thus allow to produces the heat pipe **500** in a cost-efficient manner. The grooves **502** are fabricated using production technologies that may include, but are not limited to laser machining, chemical-etching or photo-etching process, down-milling and up-milling. Further, the shape of the grooves **502** may include, but is not limited to V-shaped groove, U-shaped groove and trapezoidal-shaped groove.

[0073] FIG. 6 is a diagrammatic sectioned illustration of the heat pipe **100** in a folded state thereof with a metallic layer arranged therein, in accordance with an embodiment of the present disclosure. As illustrated, in the present embodiment, the polymeric layer **104** comprises a metallic layer **602** arranged therewith. Herein, each of the two polymeric layers **104** comprise the corresponding metallic layers **602** arranged therewith. The metallic layer **602** is in the form of a thin sheet of metal. The metallic layer **602** is impermeable to gases and prevents leakage of the working fluid to atmosphere from the internal volume in the body **102** and thus, compensate for permeability of the polymeric layer **104** to gases. For instance, the polymeric layer **104** with the metallic layer **602** has at least 20 times smaller gas permeability compared to the polymeric layer without any such metallic layer. Hence, the metallic layer **602** increases efficiency of the heat pipe **100**. The metallic layer **602** may be fabricated from metals such as copper, titanium, aluminium and a combination thereof. Alternatively, the metallic layer **602** may be fabricated from materials such as steel, stainless steel and alloys. In an embodiment, the metallic layer **602** has a thickness in a range of 0.04 to 25 µm. For example, the metallic layer **602** has thickness of about 7 µm.

[0074] In an embodiment, the metallic layer **602** is embedded in the polymeric layer **104**. Optionally, more than one metallic layer **602** may be provided with a single polymeric layer, such as the polymeric layer **104** (as shown in FIGs. 8B-8C). In such case, the metallic layer **602** may be formed on outer surfaces of the polymeric layer **104**. In an example, two metallic layers **602** may be provided, with one on each of two outer surfaces of the polymeric layer **104**. The two metallic layers may have thickness in a range of 0.04 to 25 µm and distance between the two metallic layers varies between 5 to 100 µm. For example, distance between the two metallic layers is 25 µm, with thickness of each of the two metallic layers being about 6 µm.

The metallic layer **602** may be embedded with or attached to the polymeric layer **104** using methods that may include, but are not limited to adhesive bonding of the metallic layer **602** to the polymeric layer **104**, thermal bonding of the metallic layer **602** to the polymeric layer **104**, coating the polymeric layer **104** on the metallic layer **602**, coating of the metallic layer **602** on the polymeric layer **104** using electroplating, coating of the metallic layer **602** on the polymeric layer **104** using physical vapour deposition and coating of the metallic layer **602** on the polymeric layer **104** using chemical vapour deposition.

[0075] In an embodiment, the metallic layer **602** comprises one or more indentations **604** complementary to the one or more grooves **502** formed in the foldable portion **106** of each of the first module **102A** and the second module **102B**, of the body **102**. The one or more indentations **604** are narrow depressions or cut-outs on the surface of the metallic layer **602** at the foldable portion **106** of the body **102**. Further, the indentations **604** in the metallic layer **602** are formed along the same axis along which the grooves **502** are extending at the foldable portion **106** along which the body **102** is folded during operation of the electronic device. The indentations **604** provides flexibility to the heat pipe **100** and thus, reduces the probability of formation of cracks in the metallic layer **602** at the foldable portion **106**, and thereby extend the lifetime of the heat pipe **100**. The indentations **604** are fabricated using production technologies that may include, but are not limited to, laser machining, chemical-etching or photo-etching process, down-milling and up-milling. Further, the shape of the indentations **604** may include, but is not limited, to V-shaped indentation, U-shaped indentation and trapezoidal-shaped indentation.

[0076] Optionally, in scenarios where the polymeric layer **104** comprises more than one metallic layer **602**, for example two metallic layers namely, a first metallic layer and a second metallic layer then, the one or more indentations **604** may be formed on each of the first metallic layer and the second metallic layer (as shown in FIGs. 8B-8C). Herein, the indentations **604** of the first metallic layer may be parallel to the indentations **604** in the second metallic layer. Alternatively, the indentations **604** of the first metallic layer may be staggered with respect to the indentations **604** in the second metallic layer.

[0077] FIGs. 7A and 7B are diagrammatic top planar illustrations of the metallic layer with indentations formed therein, in accordance with different embodiments of the present disclosure. As depicted in FIG. 7A, a metallic layer **700A** has indentations **702A** parallel to each other along the longitudinal direction (along axis **AA'**) of the metallic layer **700A**. Herein, in particular, eight number of indentations **702A** are formed parallel to each other in the metallic layer **700A**, but it may be appreciated that the number of indentations **702A** may vary without departing from the scope and the spirit of the present disclosure. As depicted in FIG. 7B, a metallic layer **700B** has indentations **702B** staggered with respect to each other along the longitudinal direction (along axis **AA'**) of the metallic layer **700B**. Herein, in particular, eight number of indentations **702B** are formed staggered with respect to each other in the metallic layer **700B**, but it may be appreciated that the number of indentations **702B** may vary without departing from the scope and the spirit of the present disclosure. Further, it may be contemplated that the grooves (such as the grooves **502**) may have the same arrangement as shown for indentations **702A** and **702B** herein, and the same has not been shown in the drawings for the brevity of the present disclosure.

[0078] FIGs. 8A, 8B and 8C are diagrammatic sectioned illustrations of the polymeric layer with the metallic layer having one or more indentations arranged therewith, in accordance with different embodiments of the present disclosure. Referring to FIG. 8A, a polymeric layer **800A** is depicted having a metallic layer **802A** with indentations **804A** embedded therein. Referring to FIG. 8B, a polymeric layer **800B** is depicted having two metallic layers, namely a first metallic layer **802B** and a second metallic layer **803B** arranged parallel to each other. Herein, the first metallic layer **802B** and the second metallic layer **803B** are formed on the outer surfaces of the polymeric layer **800B**. The first metallic layer **802B** has corresponding first indentations **804B** and the second metallic layer **803B** has corresponding second indentations **805B**. In the present embodiment, the first indentations **804B** and the second indentations **805B** are generally parallel with respect to each other. Referring to FIG. 8C, similar to the polymeric layer **800B** of FIG. 8B, herein a polymeric layer **800C** is depicted having two metallic layers, namely a first metallic layer **802C** and a second metallic layer **803C** arranged parallel to each other, with the first metallic layer **802C** and the second metallic layer **803C** being formed on the outer surfaces of the polymeric layer **800C**. Again, the first metallic layer **802C** has corresponding first indentations **804C** and the second metallic layer **803C** has corresponding second indentations **805C**. In the present embodiment, the first indentations **804C** and the second indentations **805C** are generally staggered with respect to each other.

[0079] FIG. 9 is a partial diagrammatic sectioned illustration of the polymeric layer having the metallic layer with the one or more indentations, showing dimensions of various elements therein, in accordance with an embodiment of the present disclosure. Herein, the first metallic layer **602A** comprises the first indentation **604A** and the second metallic layer **602B** comprises the second indentations **604B**. As shown, the first metallic layer **602A** and the second metallic layer **602B** cover the outer surfaces of the polymeric layer **104**. In the illustrated example, thickness of the polymeric layer **104** (represented as **A**) is 50 µm, thickness of each the first metallic layer **602A** and the second metallic layer **602B** (represented as **B**) is 6 µm. Further, the first metallic layer **602A** has the first indentation **604A** with length (represented as **C**) of 25 mm.

[0080] FIG. 10 is a partial diagrammatic top planar illustration of the body having the metallic layer with the one or more indentations, showing dimensions of various elements therein, in accordance with an embodiment of the present disclosure. As shown, the metallic layer **602** has the indentations **604** formed over the foldable portion **106** in the body **102**. Exemplary dimensions for the body **102** have been provided. Herein, a length of the foldable portion **106** (represented as **D**) is 25 mm and the length of each portion of the metallic layer **602** on both sides of the foldable portion **106** (represented as **E**) is 45 mm each, thus making the total length of the metallic layer **602** as 115 mm. Further, length of the body **102** along the lateral direction (represented by **F**) is 140 mm. In an example, the indentations **604** has a length of about 25 mm, width in a range of 0.5 to 50 µm and pitch in a range of 0.05 to 5.0 mm.

[0081] FIG. 11A is a diagrammatic illustration of the heat pipe **100** in the folded state with the body **102** having developed crack in a region (represented by the numeral **1100**) in the foldable portion **106**, in accordance with an embodiment of the present disclosure. FIG. 11B is an expanded illustration of the region **1100** of the foldable portion **106** of the heat pipe **100** having developed crack therein, in accordance with an embodiment of the present disclosure. As may be seen from FIG. 11B, in case of the foldable portion **106** of the heat pipe **100** having developed crack therein, permeation of the atmospheric air as well as leakage of the working fluid from internal volume goes only through the small area of the polymeric layer **104** near cracks. With the polymeric layer **104** having low permeability, the volume of permeation of the atmospheric air and/or leakage of the working fluid from internal volume would be significantly less as compared to heat pipes which may only have metallic body or may be made of polymeric material only.

[0082] Calculations are performed to prove performance of the heat pipe **100**. For calculation of performance of the heat pipe **100**, it is assumed that permeation of the atmospheric gases and the working fluid goes only through the foldable portion **106** of the heat pipe **100**. Surface area of the foldable portion **106** from where permeation of the atmospheric gases and the working fluid may occur (i.e. surface area of the crack) is assumed to be 1.5×10^{-3} m^2 and thickness of the walls is 50 µm. Hence, volume of the internal volume occupied by the working fluid is 4.7×10^{-7} m^3. For efficient performance of the heat pipe **100**, the oxygen transmission rate (OTR) of the polymeric layer is below 1.0 cc/m^2/day/bar. For calculation of OTR, assumptions are taken. The assumptions are that the working fluid is methanol, penetrated atmospheric gases separates from vapour phase of internal fluid during condensation having pressure equal to saturation pressure of the working fluid which is equal to 56 kPa, operation of the heat pipe **100** is interrupted after 3% of vapour space volume is occupied by Oxygen (from atmosphere). In such a case, volume of Oxygen inside the heat pipe is $V = 0.141 \times 10^{-7}$ m^3. Further, Oxygen in the heat pipe **100** is considered as an ideal gas, for such assumption volume of Oxygen at standard conditions (t_{st} = 0°C and p_{st} = 100 kPa) is calculated using equation 1:

$$V_{0,st} = V_0 \frac{T_{st}}{T} \frac{p}{p_{st}} \tag{1}$$

$$= 0.141 \times 10^{-7} \frac{273.15}{50 + 273.15} \frac{56}{100}$$

$$= 0.067 \times 10^{-7} m^3 = 0.0067\, cm^3$$

[0083] Further, it was assumed that required lifetime of the heat pipe **100** is 2 years. It means, that after two years' volume of Oxygen inside the heat pipe should be equal to V. Thus, required OTR of the polymeric layer **104** is estimated using equation 2:

$$OTR = \frac{V_{0,st}}{(p_{0,atm} - p_{0,int}) \times A \times \tau} \tag{2}$$

$$= \frac{0.0067}{(0.21 - 0) \times 1.5 \times 10^{-3} \times 730}$$

$$= 0.04 \frac{cm^3}{bar \times m^2 \times day}$$

[0084] Here $p_{0,atm}$ is partial pressure of Oxygen in atmosphere which is equal to 21 kPa (≈0.21 bar); $p_{0,int}$ is partial pressure of Oxygen near permeation area (it is assumed that all Oxygen is quickly removed from permeation area together with vapour flow and collected far from the permeation area) which is equal to 0 kPa and τ is required lifetime of the heat pipe **100** which is equal to 2×365 = 730 days. According to the above calculations the calculated OTR for the heat pipe **100** is 0.04 cc/m²/day/bar which is within the range hence, the heat pipe **100** provides effective heat dissipation. This provides a good compromise between the lifetime and material/production cost of the heat pipe **100**, as per embodiments of the present disclosure.

[0085] It would be appreciated that OTR less than 0.04 cc/m2/day/bar is not achievable from the existing polymer materials. It means, that if a heat pipe is fabricated using only polymer material (without any metallic body), permeation of atmospheric gases and leakage of the working fluid will occur through whole of the polymeric layer and required lifetime for the heat pipe will be not achievable. However, the heat pipe **100** of the present disclosure comprises the body **102** which is impermeable for gases as the body **102** is fabricated using a metallic material and permeation will only occur through the polymeric layer **104** near the cracks.

Calculations are performed to determine location of the crack formed in the body **102**. For calculation, it is assumed, that permeation surface of the polymeric layer **104** is equal to surface of cracks in the body **102**. For exemplary calculations, we used a polymeric film comprising 3 polymeric layers of polymers with a layer of ethylene vinyl alcohol (EVOH) sandwiched between two polyethylene layers (PE) (PE/ EVOH / PE). Measured OTR of the polymeric film according to equation 2 is 0.55 cc/m2/day/bar. Such value of OTR of the polymeric film will be acceptable if total surface of cracks in the body **102** will be 0.11×10^{-3} m^2. Therefore, surface of the crack in the body **102** on the foldable portion **106** should be less than 7% of surface of permeation area. For such conditions, if width of the crack is 5 μm, cracks could be located on the distance greater than 70 μm. Such distribution of the crack may be controlled by the one or more grooves **502** on the body **102**, which avoid formation of large cracks and control the location of formation of the crack on the body **102**.

[0086]Measurement of OTR after folding the foldable portion **106** about 200 000 times with radius 3 mm are performed for the polymeric (polyimide) layer **104**, for both with and without the metallic (copper) layer **602**. Measurement method is based on the equations 1 and 2. The measured OTR for the polymeric layer **104** without the metallic layer **602** is 186 cc/m2/day/bar. However, the OTR with the polymeric layer **104** with the metallic layer **602** was calculated to 9.3 cc/m2/day/bar. Though, it is far from target of OTR less than 0.05 cc/m2/day/bar, however already gives 20 times of improvement. Assuming, that metallic layer gives decreasing of OTR by 20 times, we can calculate OTR for another polymers. When the polymer (polyimide) layer **104** was replaced with a multi layered polymeric layer of ethylene vinyl alcohol (EVOH) sandwiched between two polyethylene layers (PE) (PE/ EVOH / PE), calculated OTR was 0.028 cc/m2/day/bar (0.55 / 20 = 0.028 cc/m2/day/bar) which is less than required OTR of 0.04 cc/m2/day/bar. Herein, 0.55 cc/m2/day/bar is measured value of OTR for PE/EVOH/PE multi-layered polymer. Hence, the at least one metallic layer **104** provides balance between flexibility and gas permeability to the polymeric layer **104**.

[0087]FIG. 12 is a flowchart of a method **1200** for manufacturing a heat pipe (such as the heat pipe **100**), in accordance with an embodiment of the present disclosure. At step **1202**, the body **102** is fabricated by joining together a first module **102A** and a second module **102B** to define an internal volume, with each of the first module **102A** and the second module **102B** having a foldable portion **106** therein. At step **1204**, a polymeric layer **104** is bonded over the foldable portion **106** of each of the first module **102A** and the second module **102B**, of the body **102**.

[0088]The present disclosure also relates to the method **1200** as described above. Various embodiments and variants disclosed above apply mutatis mutandis to the method **1200**.

[0089] In an embodiment, the method **1200** comprises disposing the polymeric layer **104** to cover an outer surface of each of the first module **102A** and the second module **102A**, of the body **102**. The use of polymeric layer **104** over entire outer surface of each of the first module **102A** and the second module **102A**, and not just the foldable portions **106** thereof, provides balanced permeability and flexibility to the heat pipe **100**, while making the fabrication process simpler.

[0090] In an embodiment, the method **1200** comprises forming one or more grooves **502** in the foldable portion **106** of each of the first module **102A** and the second module **102B** of the body **102**, extending along the lateral direction (along the axis **BB'**) of the body **102**. The formation of grooves **502** reduces overall weight of the body **102** and reduces material usage for production of the heat pipe **100** making the manufacturing more cost-effective. The grooves **502** further allow bending of the heat pipe **100** while reducing formation of large cracks in the body **102** of the heat pipe **100**. Further, the grooves **502** controls the location of formation of cracks by restricting the cracks around the foldable portion **106** in the heat pipe **100**.

[0091] In an embodiment, the method **1200** comprises arranging a metallic layer **602** with the polymeric layer **104**. Use of the metallic layer **602** provides form to the polymeric layer **104** for easy bonding to the body **102** and further significantly reduce leakage of the working fluid from the internal volume through the polymeric layer **104**.

[0092] In an embodiment, the method **1200** comprises forming one or more indentations **604** in the metallic layer **602** complementary to the one or more grooves **502** formed in the foldable portion **106** of each of the first module **102A** and the second module **102B**, of the body **102**. The formation of indentations **604** reduces overall weight of the metallic layer **604** and reduces material usage for production of the heat pipe **100**, making the manufacturing more cost-effective. The indentations **604** in the metallic layer **602** also reduce formation of cracks in the metallic layer **602** on folding of the heat pipe **100**.

[0093] Further, the method **1200** comprises charging the heat pipe, i.e. filling the liquid coolant inside the fabricated heat pipe (such as, the heat pipe **100**). Charging of the heat pipe may be performed at any one of two stages: after fabrication of the body; or after bonding of the polymer layer.

[0094] The electronic device, as referred herein, comprises (incorporates) the heat pipe **100**. Herein, the electronic device refers to a device that comprises components such as a passive component or an active component, semiconductor, interconnect, contact pad, transistor, diode, LED, and the like connected together to form integrated circuits in order to perform a task. For example, the electronic device may include, but is not limited to laptops, mobile phones, desktop computers, smart phones, mobile tablets, camera, printer and radio. Further, the electronic device may be a foldable device that may be folded during operation. Different components of the electronic device generate heat, thus the electronic device requires a cooling system to improve reliability and prevent premature failure of the electronic device. Further, junction temperature of integrated circuits has to be maintained below the allowable limit specified for both performance and reliability factor. The heat pipe **100** of the present disclosure is placed near heat generating component of the electronic device to dissipate heat in the electronic device. For foldable electronic device, the heat pipe **100** can bend along with bending of the electronic device and does not break during folding of the electronic device. Further, the heat pipe **100** provides effective heat dissipation even in the folded state of the electronic device. The heat pipe **100** of the present disclosure with the body **102** having metallic structure and the external polymeric layer **104** provides a balanced flexibility and lifetime (permeation rate of air and leakages of internal fluid).

[0095] Modifications to embodiments of the present disclosure described in the foregoing are possible without departing from the scope of the present disclosure as defined by the accompanying claims. Expressions such as "including", "comprising", "incorporating", "have", "is" used to describe and claim the present disclosure are intended to be construed in a non-exclusive manner, namely allowing for items, components or elements not explicitly described also to be present. Reference to the singular is also to be construed to relate to the plural. The word "exemplary" is used herein to mean "serving as an example, instance or illustration". Any embodiment described as "exemplary" is not necessarily to be construed as preferred or advantageous over other embodiments and/or to exclude the incorporation of features from other embodiments. The word "optionally" is used herein to mean "is provided in some embodiments and not provided in other embodiments". It is appreciated that certain features of the present disclosure, which are, for clarity, described in the context of separate embodiments, may also be provided in combination in a single embodiment. Conversely, various features of the invention, which are, for brevity, described in the context of a single embodiment, may also be provided separately or in any suitable combination or as suitable in any other described embodiment of the disclosure.

CLAIMS

1. A heat pipe (100) for an electronic device, comprising:

a body (102) having a generally planar, metallic structure, the body (102) comprising a first module (102A) and a second module (102B) joined together to define an internal volume, wherein each of the first module (102A) and the second module (102B) has a foldable portion (106) therein; and

a polymeric layer (104) disposed over the foldable portion (106) of each of the first module (102A) and the second module (102B), of the body (102).

2. A heat pipe (100) according to claim 1, wherein the first module (102A) comprises a plurality of projections located inside the internal volume.

3. A heat pipe (100) according to claim 2, wherein the plurality of projections comprises a first set of projections (202A) and a second set of projections (202B), and wherein the second set of projections (202B) is arranged on the foldable portion (106) of the first module (102A) and extend along a longitudinal direction of the body (102).

4. A heat pipe (100) according to any one of claims 2 to 3 further comprising a porous layer (204) having a plurality of holes complementary to the plurality of projections in the first module (102A), such that the porous layer (204) is arranged on the first module (102A) inside the internal volume.

5. A heat pipe (100) according to any one of preceding claims further comprising one or more grooves (502) formed in the foldable portion (106) of each of the first module (102A) and the second module (102A) of the body (102), wherein the one or more grooves (502) extends along a lateral direction of the body (102).

6. A heat pipe (100) according to any one of preceding claims, wherein the polymeric layer (104) covers an outer surface of each of the first module (102A) and the second module (102B), of the body (102).

7. A heat pipe (100) according to any one of preceding claims, wherein the polymeric layer (104) comprises a metallic layer (602) arranged therewith.

8. A heat pipe (100) according to claims 5 and 7, wherein the metallic layer (602) comprises one or more indentations (604) complementary to the one or more grooves (502)

formed in the foldable portion (106) of each of the first module (102A) and the second module (102B), of the body (102).

9. A heat pipe (100) according to any one of claims 7 to 8, wherein the metallic layer (602) is embedded in the polymeric layer (104).

10. A heat pipe (100) according to any one of preceding claims, wherein the body (102) is fabricated by at least one of: sintering, soldering and welding process.

11. A heat pipe (100) according to any one of preceding claims, wherein the polymeric layer (104) is formed of: polyimides, polyethylene terephthalate, polyethylene naphthalate, ethylene vinyl alcohol, polyamide, polyvinylidene chloride, polyacrylonitrile, nylon, or a combination thereof.

12. A heat pipe (100) according to any one of preceding claims, wherein the polymeric layer (104) is bonded to the body (102) using at least one of: adhesive bonding, low temperature diffusion bonding, coating and selective laser welding.

13. A heat pipe (100) according to any one of preceding claims, wherein the body (102) has a thickness in a range of 50 to 500 μm, and wherein the polymeric layer (104) has a thickness in a range of 15 to 200 μm.

14. A heat pipe (100) according to any one of claims 7 to 9, wherein the metallic layer (602) has a thickness in a range of 0.04 to 25 μm.

15. A method (1200) for manufacturing a heat pipe (100) for use in electronic devices, the method comprising:

fabricating a body (102) by joining together a first module (102A) and a second module (102B) to define an internal volume, with each of the first module (102A) and the second module (102B) having a foldable portion (106) therein; and

bonding a polymeric layer (104) over the foldable portion (106) of each of the first module (102A) and the second module (102B), of the body (102).

16. A method (1200) according to claim 15 further comprising disposing the polymeric layer (104) to cover an outer surface of each of the first module (102A) and the second module (102B), of the body (102).

17. A method (1200) according to any one of claims 15 to 16 further comprising forming one or more grooves (502) in the foldable portion (106) of each of the first module (102A) and the second module (102B) of the body (102), extending along a lateral direction of the body (102).

18. A method (1200) according to any one of claims 15 to 17 further comprising arranging a metallic layer (602) with the polymeric layer (104).

19. A method (1200) according to claim 18 further comprising forming one or more indentations (604) in the metallic layer (602) complementary to the one or more grooves (502) formed in the foldable portion (106) of each of the first module (102A) and the second module (102B), of the body (102).

20. An electronic device comprising a heat pipe (100) according to any one of claims 1-14.

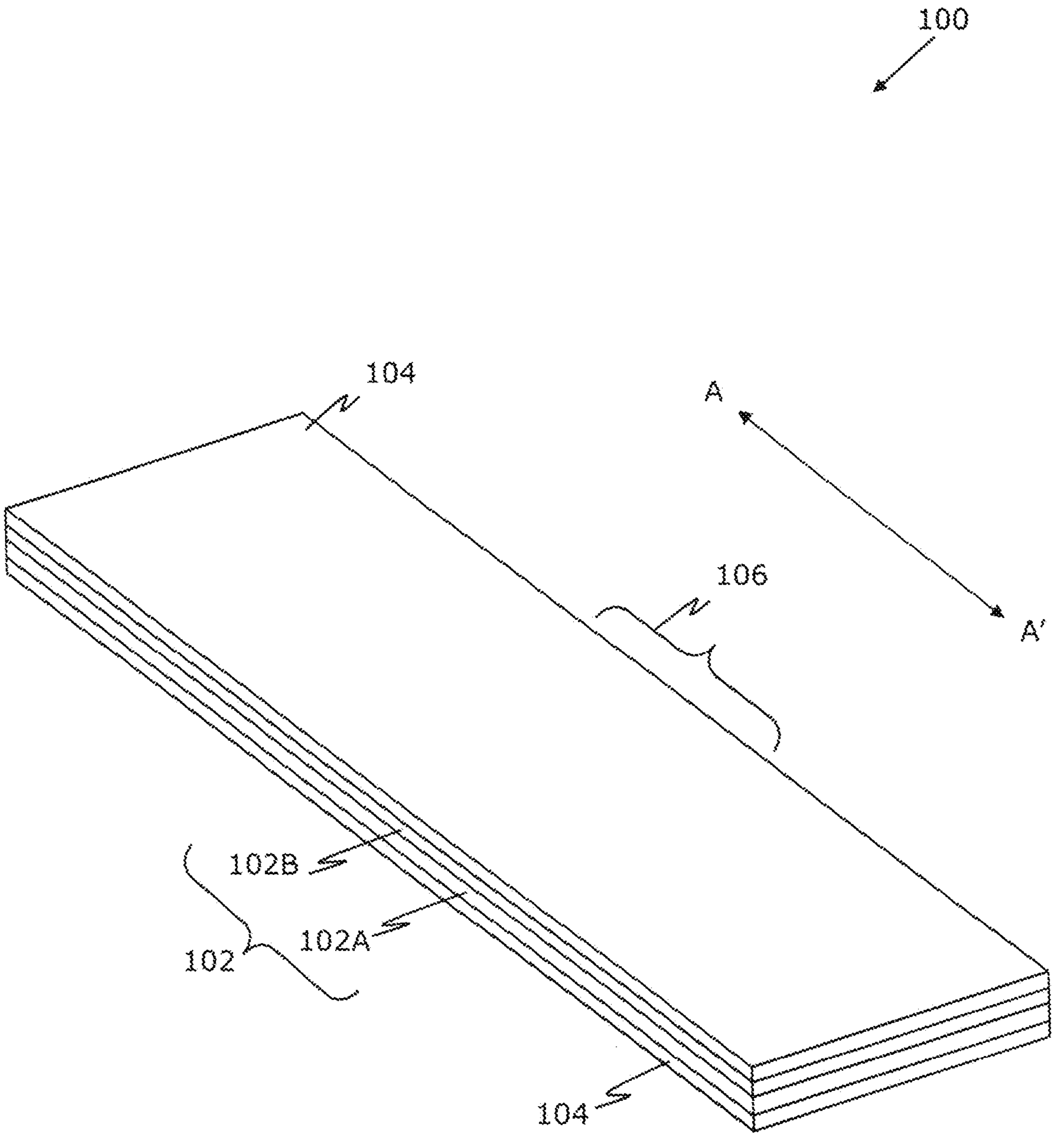

FIG. 1A

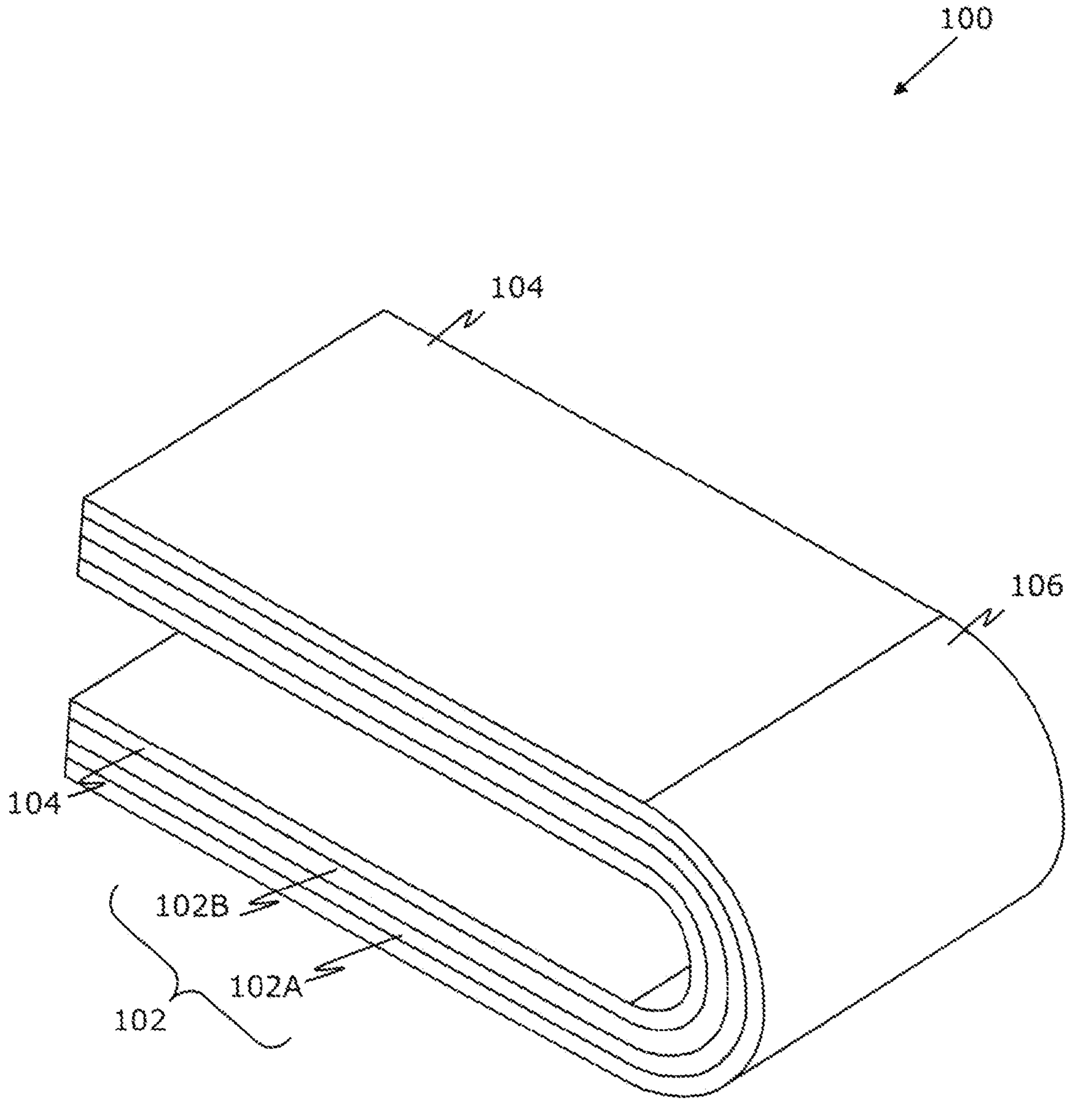

FIG. 1B

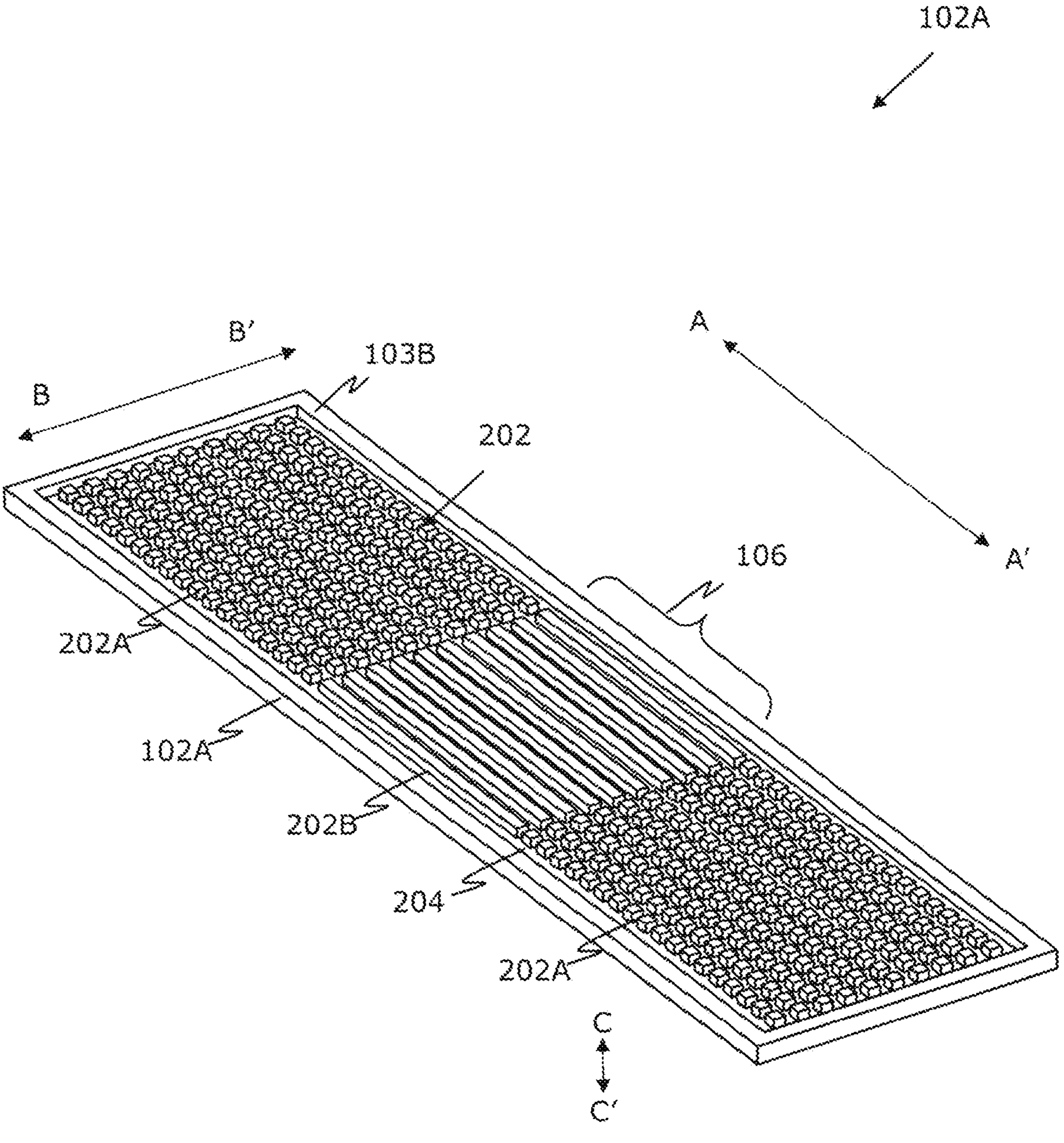

FIG. 2A

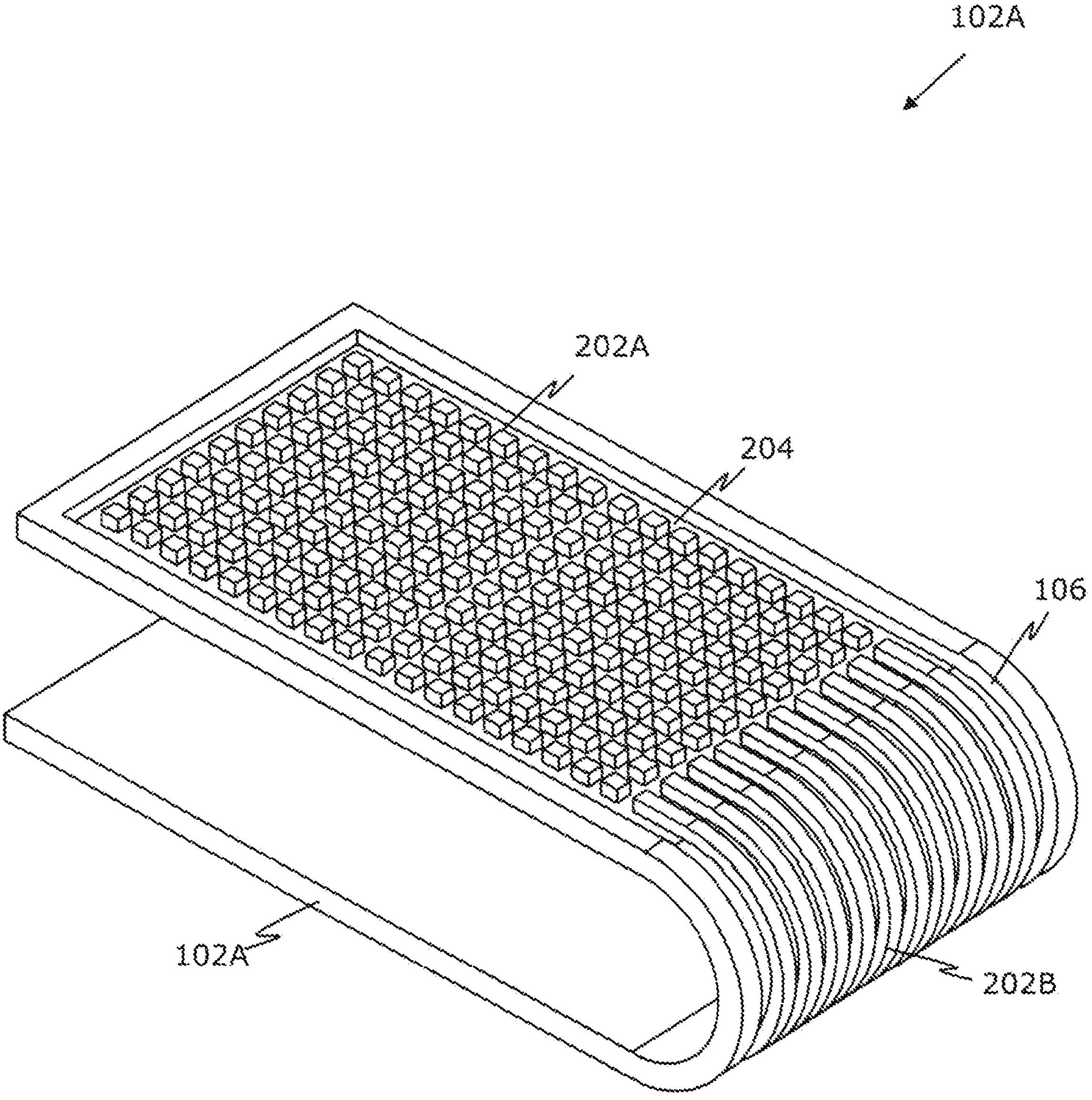

FIG. 2B

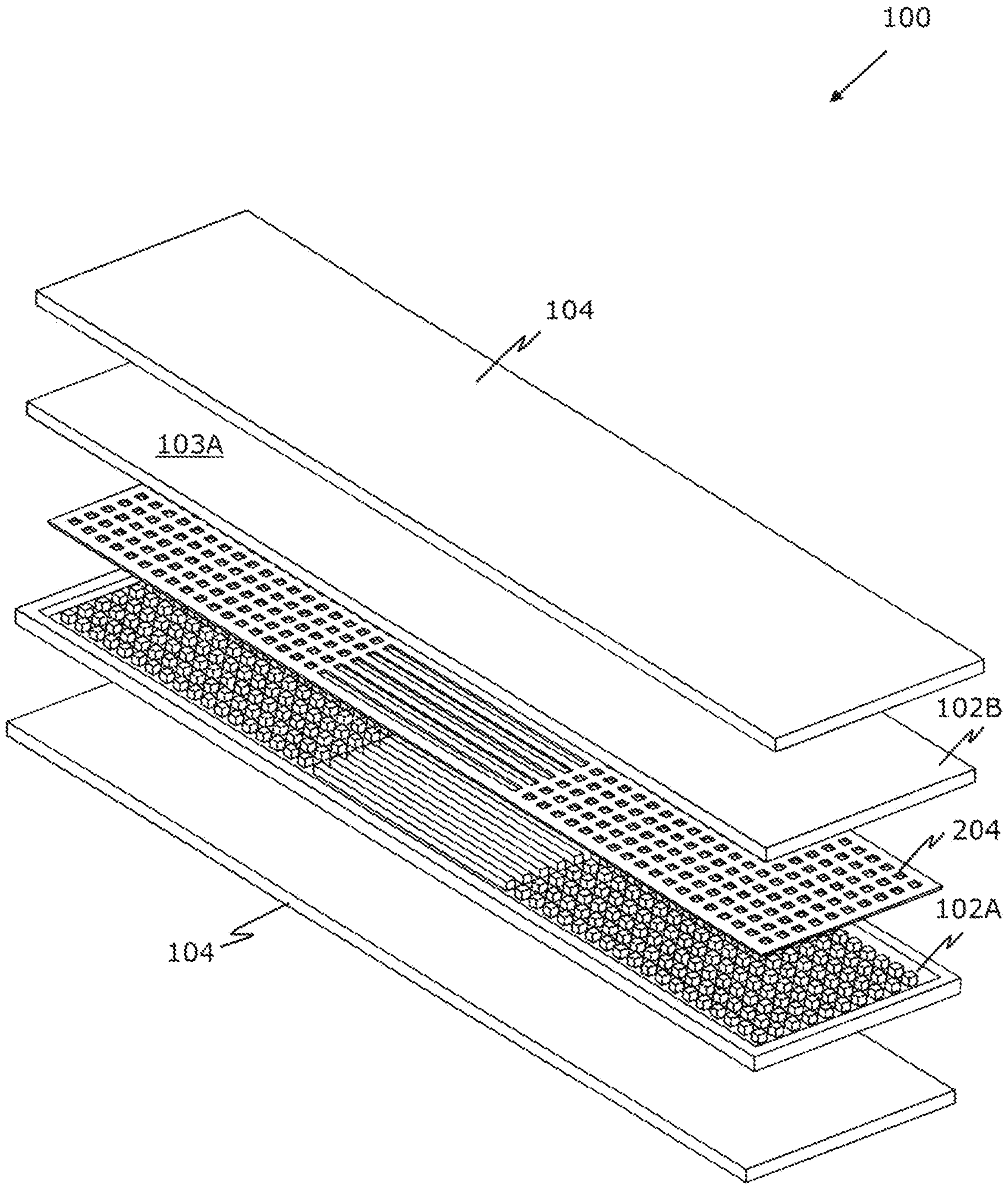

FIG. 3A

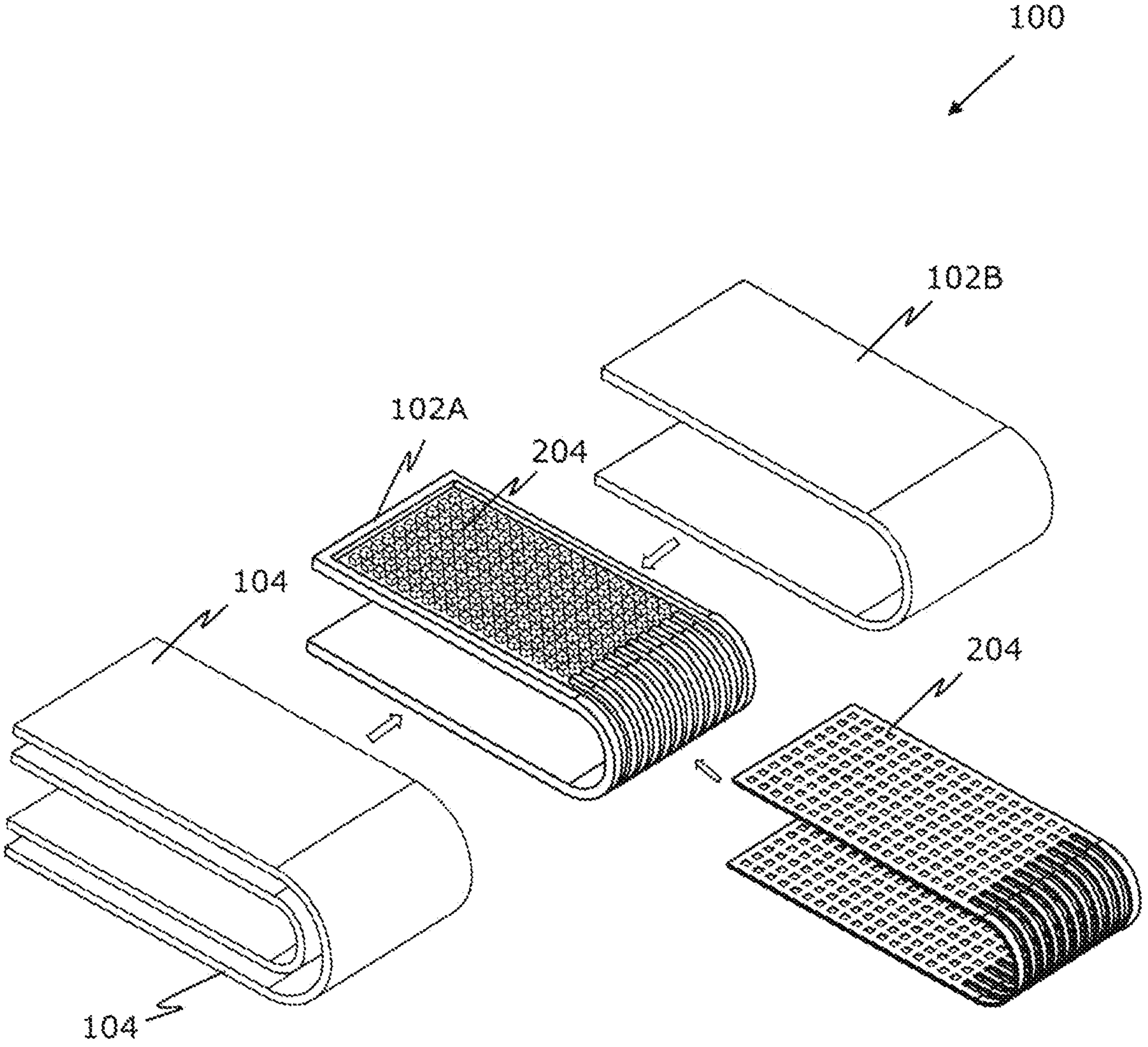

FIG. 3B

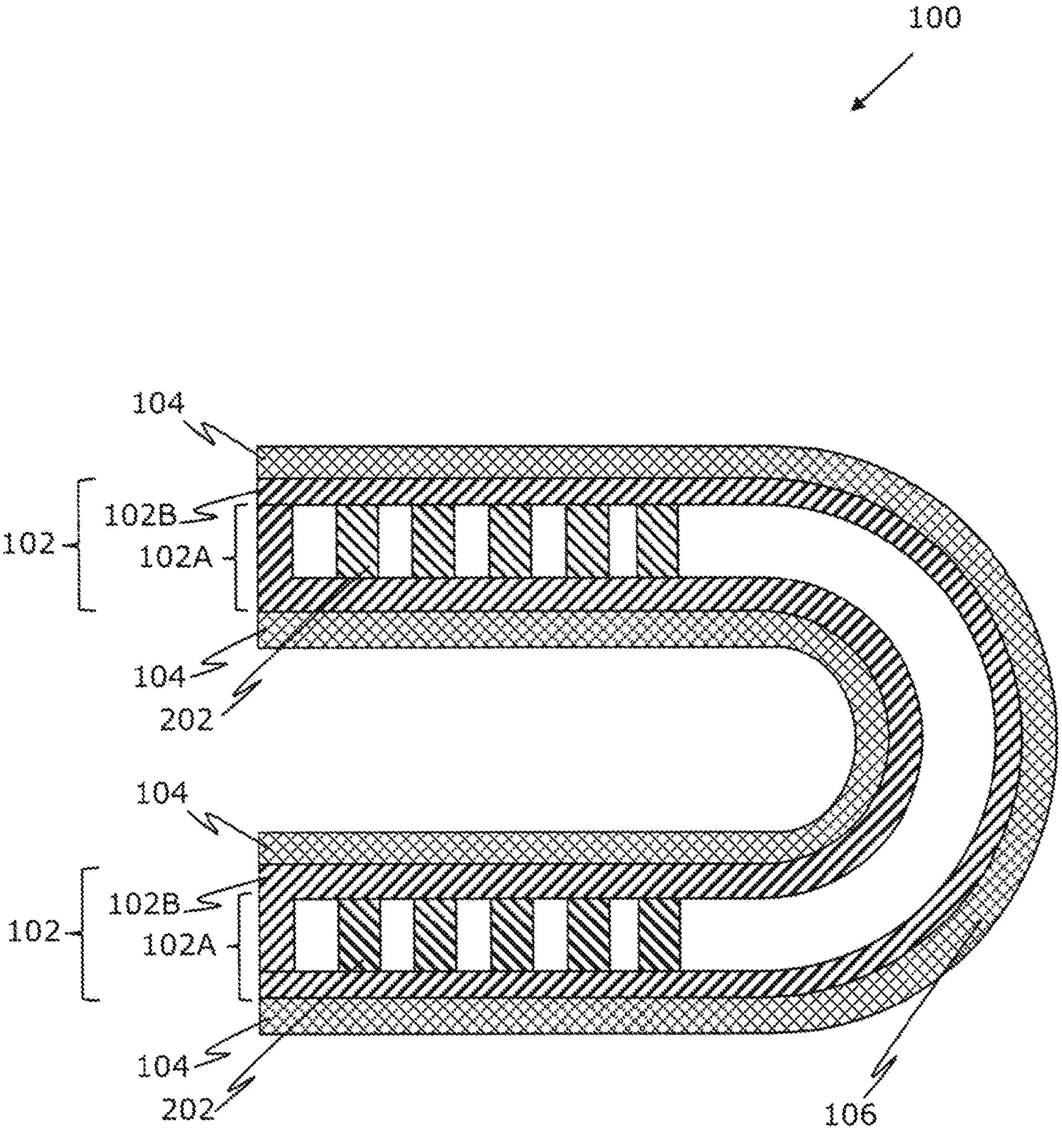

FIG. 4

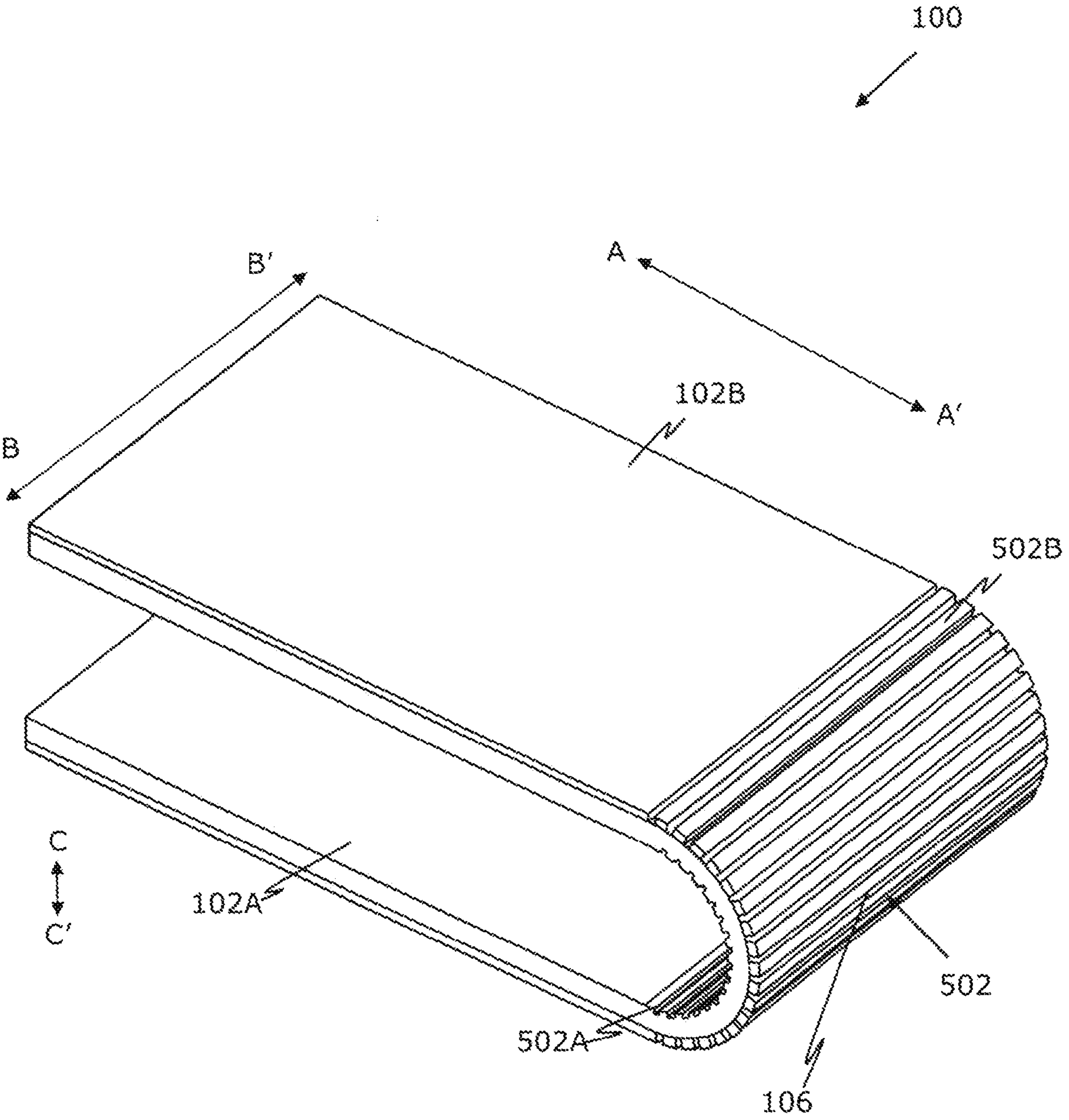

FIG. 5

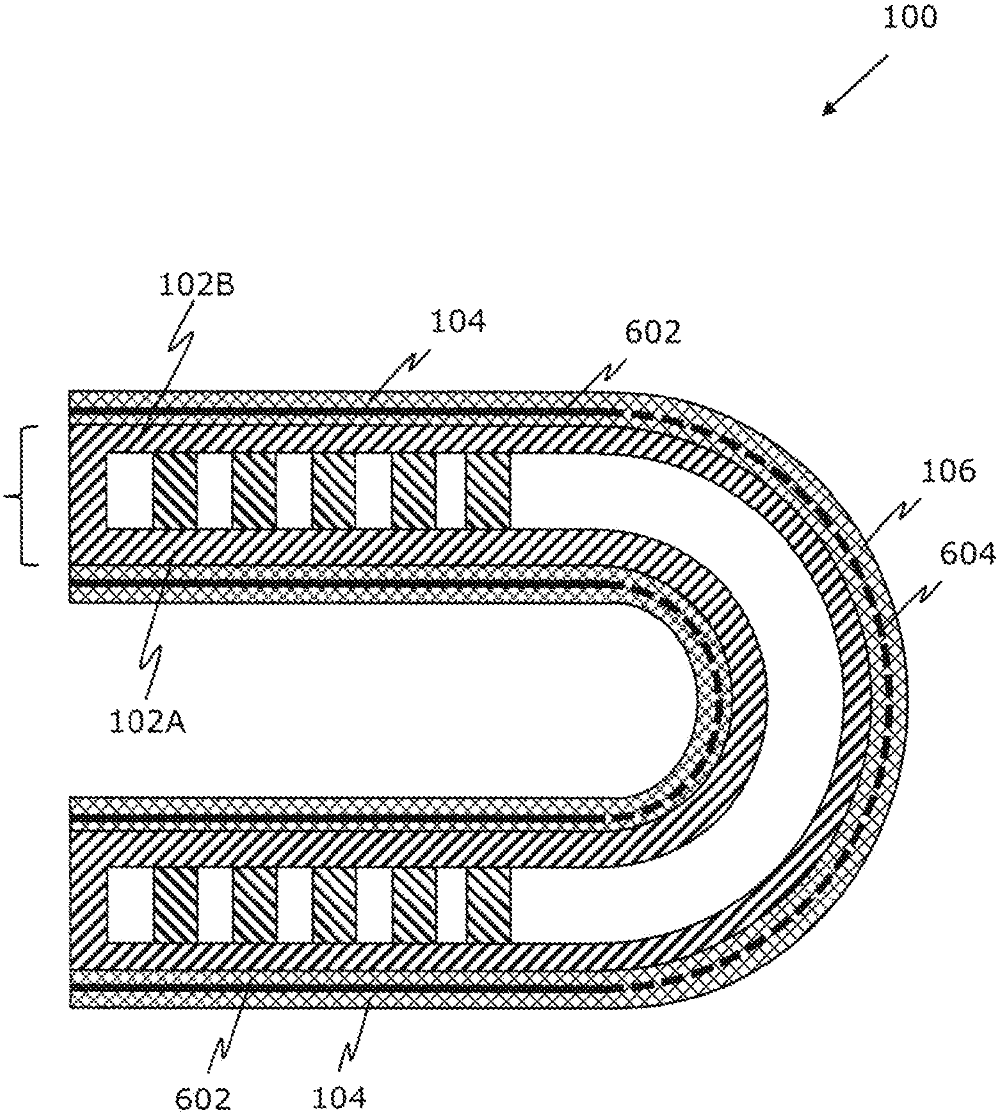

FIG. 6

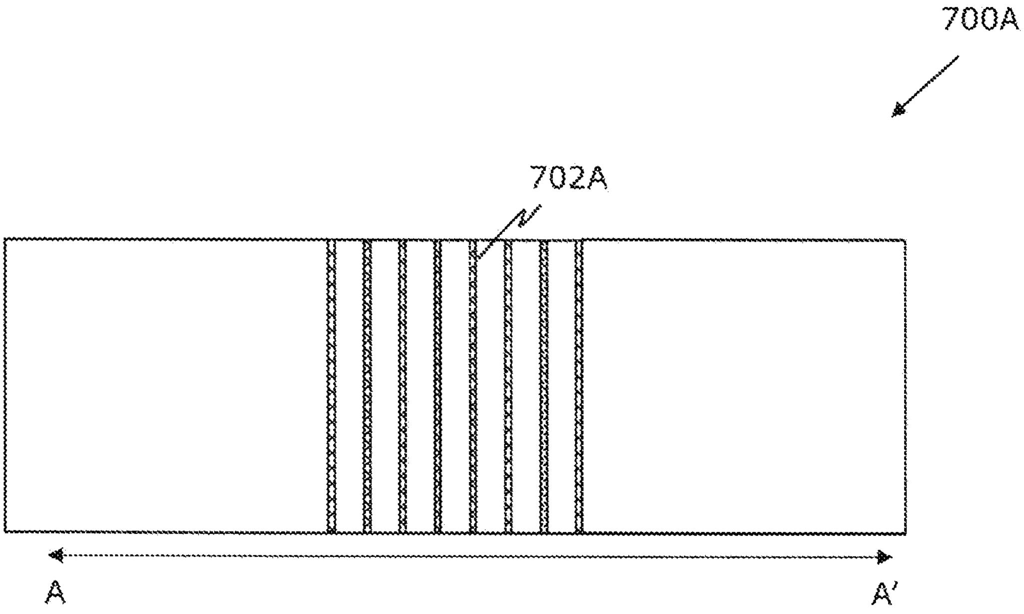

FIG. 7A

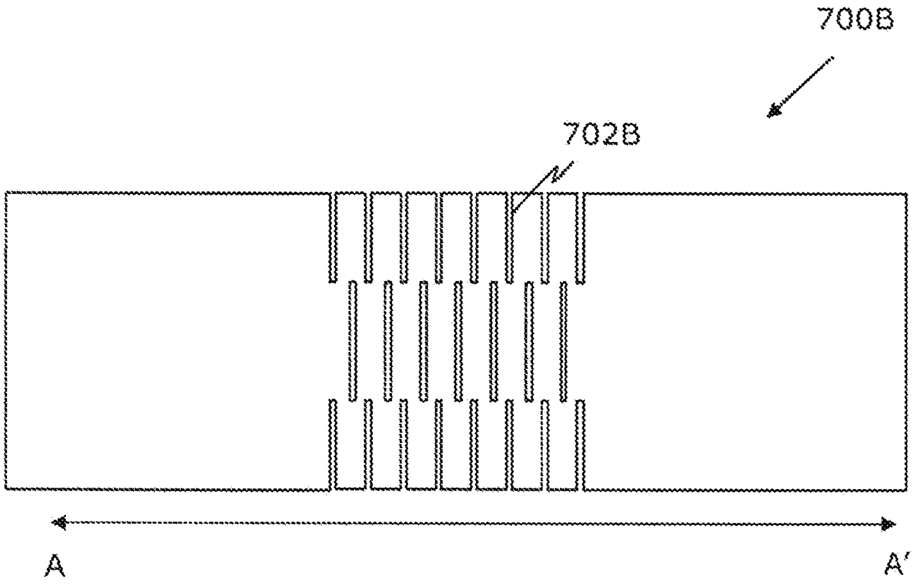

FIG. 7B

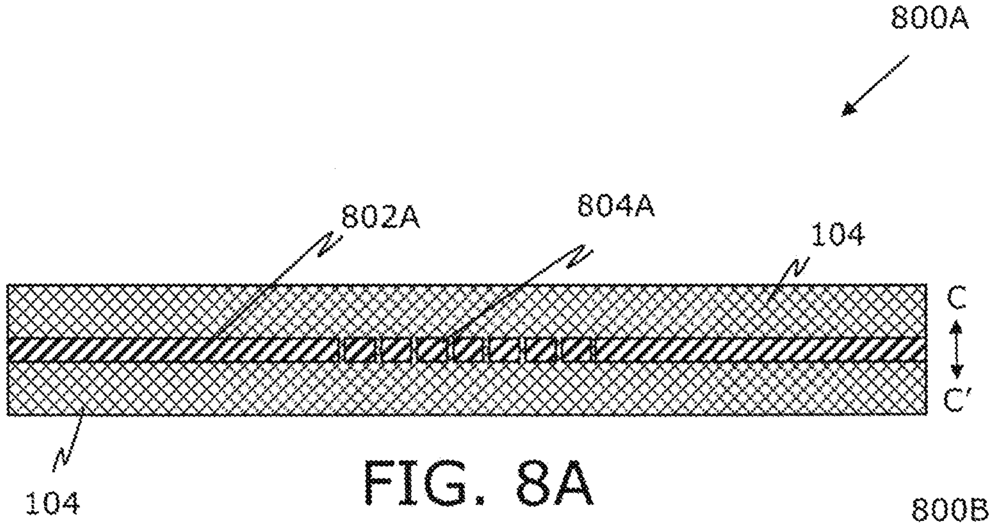

FIG. 8A

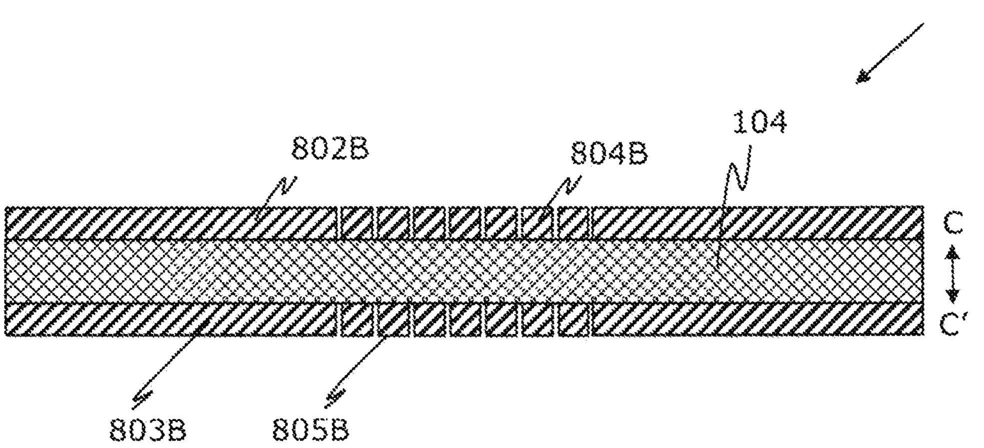

FIG. 8B

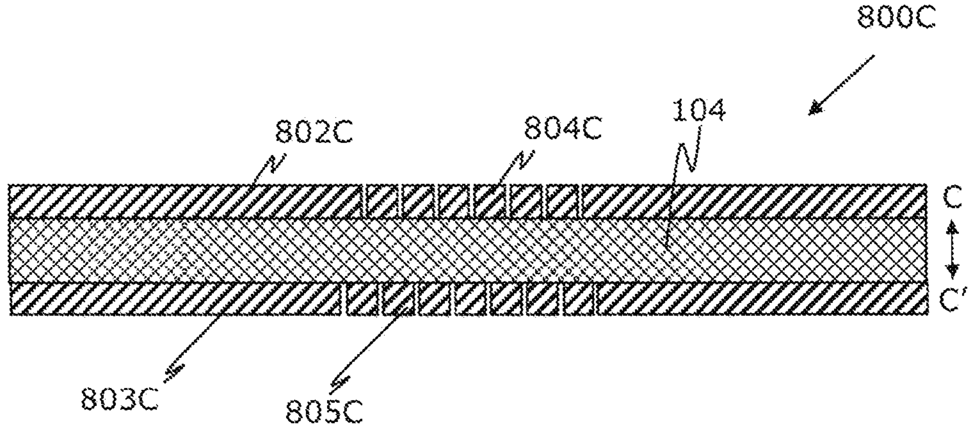

FIG. 8C

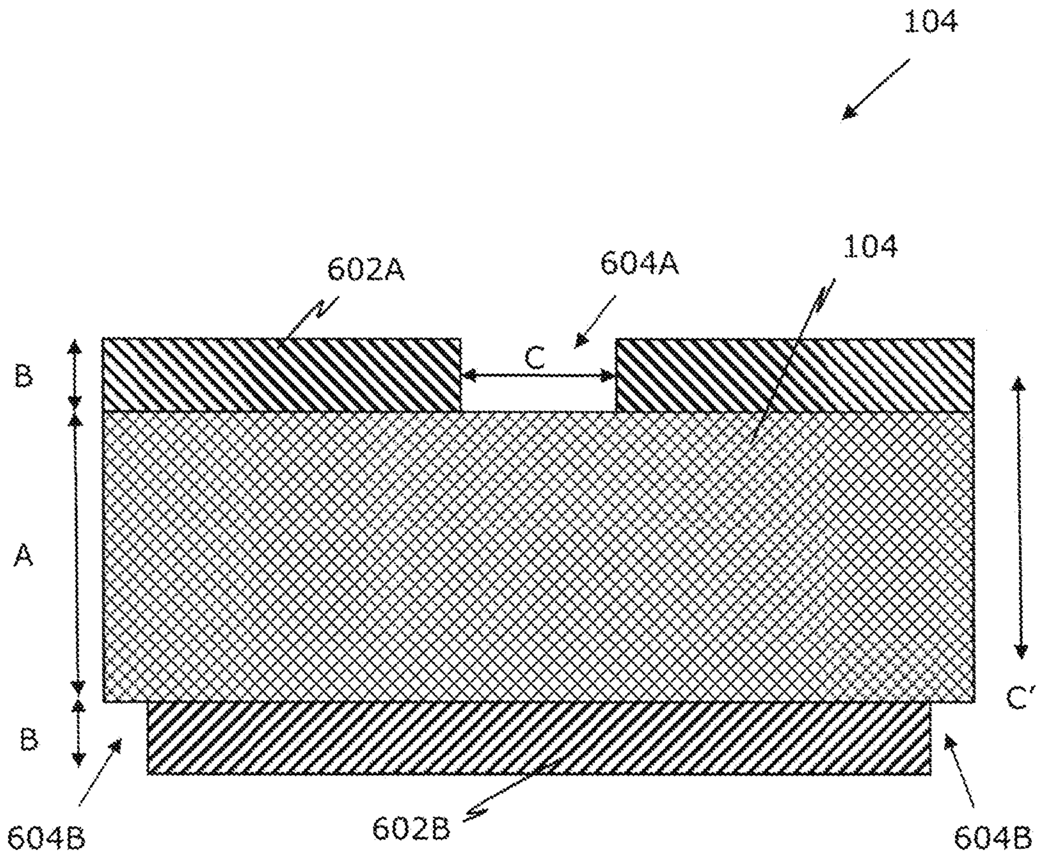

FIG. 9

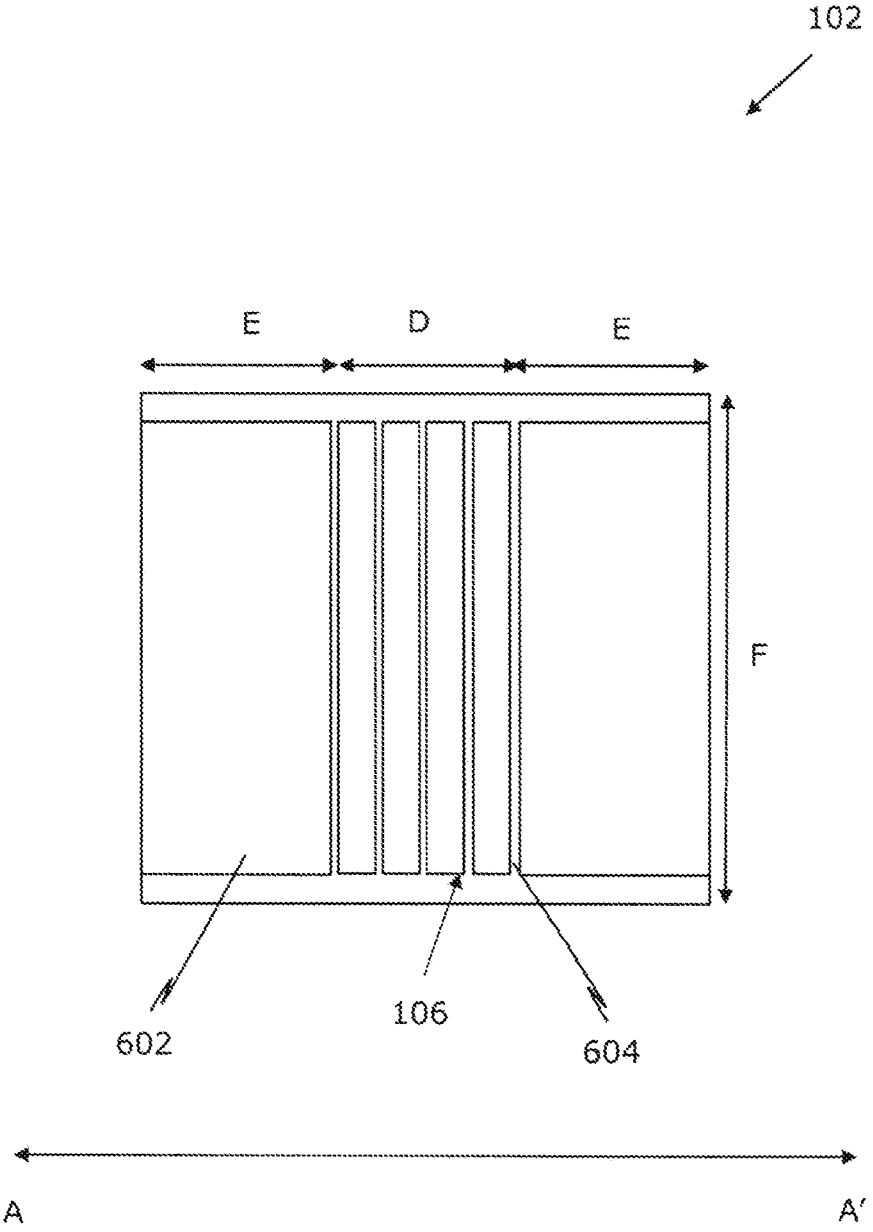

FIG. 10

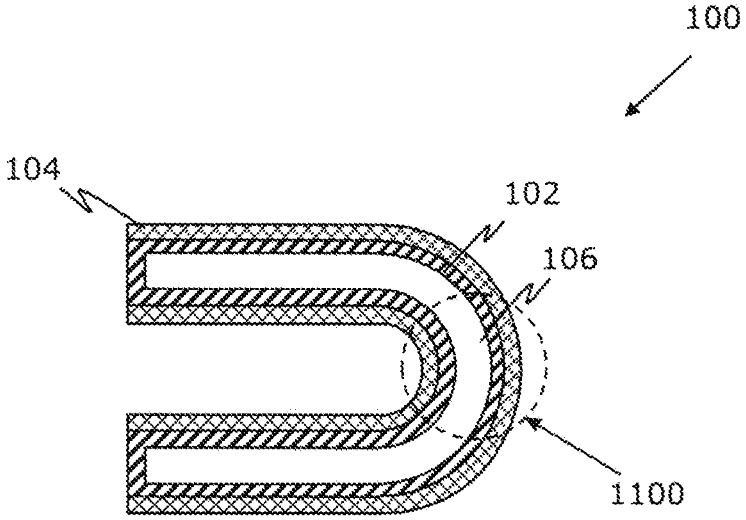

FIG. 11A

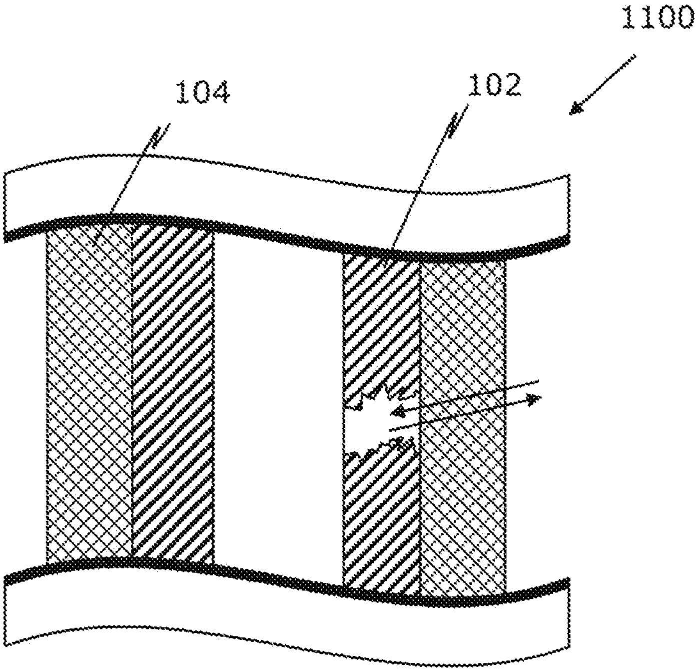

FIG. 11B

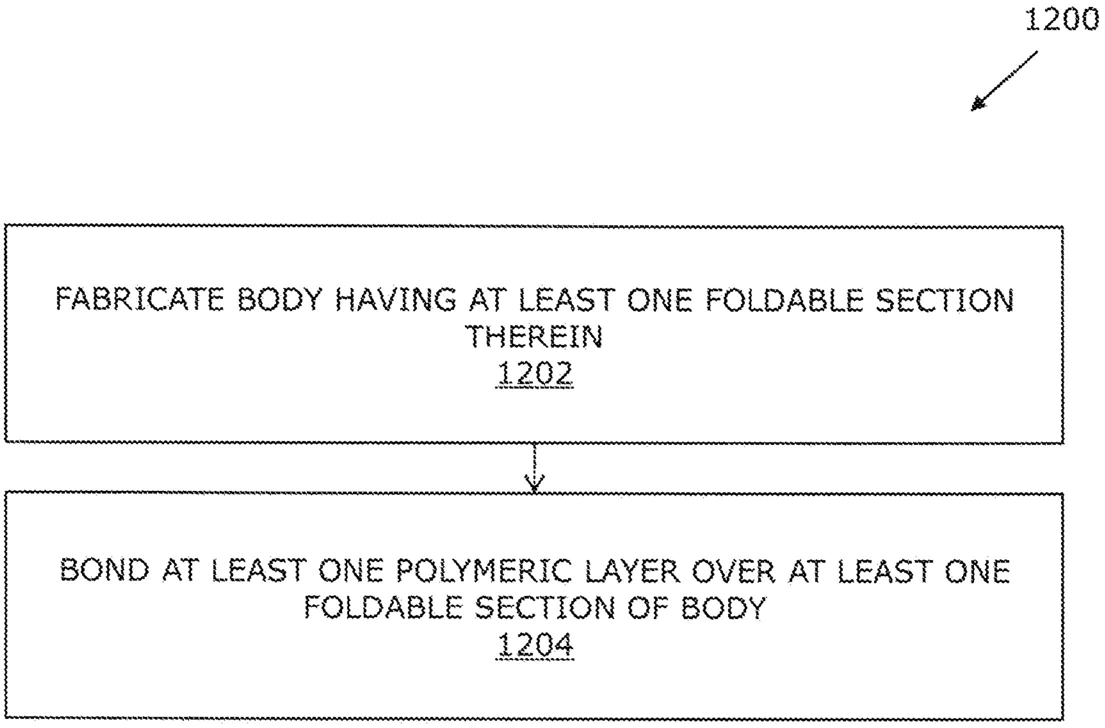
1200
FABRICATE BODY HAVING AT LEAST ONE FOLDABLE SECTION THEREIN
1202
BOND AT LEAST ONE POLYMERIC LAYER OVER AT LEAST ONE FOLDABLE SECTION OF BODY
1204

FIG. 12

INTERNATIONAL SEARCH REPORT

International application No
PCT/BY2020/000004

A. CLASSIFICATION OF SUBJECT MATTER
INV. F28D15/02
ADD.

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)
F28D

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

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

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2018/299206 A1 (KIM SUNG JIN [KR] ET AL) 18 October 2018 (2018-10-18) figure 4a -----	1-20
X	JP 2007 147226 A (MATSUSHITA ELECTRIC IND CO LTD) 14 June 2007 (2007-06-14) paragraph [0024] -----	1,15,20
X	US 2009/071632 A1 (BRYANT JOHNNY P [US] ET AL) 19 March 2009 (2009-03-19) claims 1,3,4; figure 3 -----	1,15,20

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

☒ See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"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
3 February 2021

Date of mailing of the international search report
11/02/2021

Name and mailing address of the ISA/
European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040,
Fax: (+31-70) 340-3016

Authorized officer
Bain, David

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/BY2020/000004

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2018299206 A1	18-10-2018	KR 101801823 B1 US 2018299206 A1	27-11-2017 18-10-2018
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US 2009071632 A1	19-03-2009	NONE	