(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
15 August 2019 (15.08.2019)

WIPO | PCT

(10) International Publication Number
WO 2019/156667 A1

(51) International Patent Classification:
B29C 70/88 (2006.01) *B29C 70/68* (2006.01)
C09K 3/00 (2006.01) *H01R 4/01* (2006.01)

(21) International Application Number: PCT/US2018/017338

(22) International Filing Date: 08 February 2018 (08.02.2018)

(25) Filing Language: English

(26) Publication Language: English

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(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

(54) **Title:** SHAPE MEMORY COMPOSITES

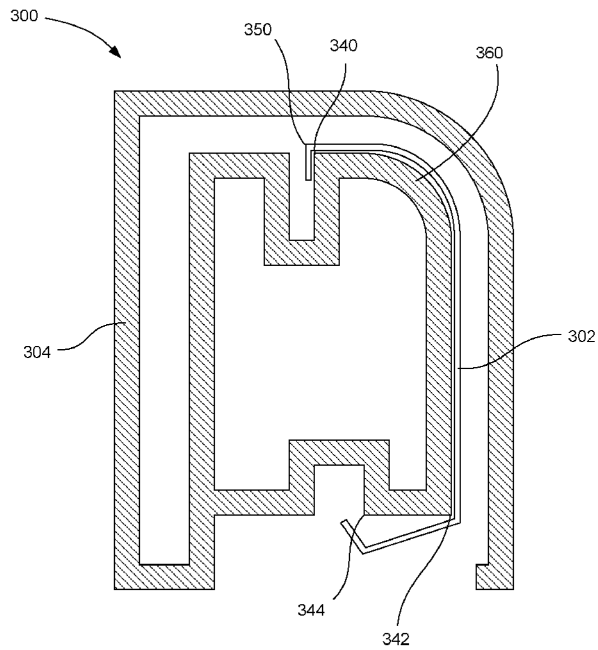

FIG. 4

(57) **Abstract:** A shape memory composite can, in one example, include a shape memory material to bend along a fold region in response to a phase change in the shape memory material from a first phase to a second phase. A mechanochromic marking can be deposited on a surface of the shape memory material at the fold region. The mechanochromic marking can change color along the fold region in response to the bending of the shape memory material.

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Declarations under Rule 4.17:
— *as to the identity of the inventor (Rule 4.17(i))*
— *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*

Published:
— *with international search report (Art. 21(3))*

SHAPE MEMORY COMPOSITES

BACKGROUND

[0001] Shape memory materials, such as shape memory alloys and shape memory polymers, can return from a deformed, temporary shape to a “memory” or pre-stressed or pre-deformed shape in response to a stimulus such as a temperature change. For example, some shape memory alloys can be deformed from a memory shape to a deformed shape and then return to the memory shape when the shape memory alloy is heated to cause a phase change in the shape memory alloy. Some shape memory materials can exhibit different properties in different phases. For example, some shape memory materials can be stiffer and stronger in a high temperature phase and more malleable in a low temperature phase.

BRIEF DESCRIPTION OF THE DRAWINGS

[0002] FIG. 1 is a schematic view of an example shape memory composite in accordance with an example of the present disclosure;

[0003] FIGs. 2A-2C are perspective views of an example shape memory composite in three states of bending, in accordance with an example of the present disclosure;

[0004] FIG. 3 is a cross-sectional view of an example multi-component system in accordance with an example of the present disclosure;

[0005] FIG. 4 is a cross-sectional view of an example multi-component system in accordance with an example of the present disclosure;

[0006] FIG. 5 is a cross-sectional view of an example multi-component system in accordance with an example of the present disclosure;

[0007] FIG. 6 is a flowchart illustrating an example of the function of a shape memory composite in accordance with an example of the present disclosure; and

[0008] FIG. 7 is a flowchart of an example method of making a multi-component system in accordance with an example of the present disclosure.

[0009] The figures depict several examples of the presently disclosed technology. However, it should be understood that the present technology is not limited to the examples depicted.

DETAILED DESCRIPTION

[0010] The present disclosure is drawn to shape memory composites, multi-component systems that include shape memory composites, and methods of making such multicomponent systems. In certain examples, a shape memory composite can include a shape memory material to bend along a fold region in response to a phase change in the shape memory material from a first phase to a second phase. A mechanochromic marking can be deposited on a surface of the shape memory material at the fold region. The mechanochromic marking can change color along the fold region in response to the bending of the shape memory material. Thus, the term “composite” is used because the shape memory composite includes two materials, namely the shape memory material and the mechanochromic marking.

[0011] In some examples, the shape memory material can be in the form of a flat layer prior to the phase change from the first phase to the second phase. In further examples, the shape memory material can include a shape memory alloy or a shape memory polymer. In certain examples, the bending of the shape memory material can be reversible by a phase change in the shape memory material from the second phase back to the first phase.

[0012] The mechanochromic marking can change color in response to bending of the shape memory material. In some cases, this color change can make the fold region observable. In specific examples, the mechanochromic marking can making the fold region become observable by changing from colorless to colored, changing from colored to colorless, changing from a first color to a second color, or changing color such that the color change is observable by an infrared or ultraviolet sensor. In some examples, the mechanochromic marking can be a mechanochromic ink printed onto the shape memory material.

[0013] In further examples, a multi-component system can include an object having a corner and a shape memory composite located proximate to the corner. The shape memory composite can include a shape memory material to bend along a fold region in response to a phase change in the shape memory material from a first phase to a second phase. The shape memory material can bend around the corner of the object. A mechanochromic marking can be deposited on a surface of the shape memory material at the fold region. The mechanochromic marking can change color along the fold region in response to the bending of the shape memory material. In a particular example, the corner of the object can have an angle greater than a bend angle of the shape memory composite achieved by the bending of the shape memory composite in response to the phase change of the shape memory material alone. In a further example, the shape memory material can be bent farther at the fold region after the phase change by application of an external force such that the bend angle is increased. In one such example, the fold region can be accessible when in place proximate to the corner of the object so that an external force can be applied to the fold region.

[0014] In some examples, the shape memory composite can be a portion of a thermal management system, an electromagnetic interference remediation system, a radio frequency interference remediation system, an auxetic shock absorption system, or a combination thereof.

[0015] In further examples, a method of making a multi-component system can include inserting a shape memory composite into a space with an object. The shape memory composite can include a shape memory material and a mechanochromic marking deposited on a surface of the shape memory material at a fold region. The shape memory composite can bend along the fold region in response to a phase change in the shape memory material from a first phase to a second phase. The object can include a corner located proximate to the shape memory composite when inserted. The temperature of the shape memory material can be changed to cause the phase change in the shape memory material from the first phase to the second phase and the bend along the fold region. The mechanochromic marking can change color along the fold region in response to the bending of the shape memory material.

[0016] In certain examples, an external force can be applied to the shape memory composite to bend farther at the fold region so that a bend angle of the shape memory composite is increased. The shape memory composite can bend around the corner of the object. In some examples, the changing of the temperature of the shape memory material and the applying of an external force to the shape memory composite can be performed while the shape memory composite is inserted in the object. In other examples, the changing of the temperature of the shape memory material and the applying external force to the shape memory composite can be performed before inserting the shape memory composite into the object. The phase change can then be reversed and the bend can be partially unbent in the shape memory material before inserting the shape memory composite into the object.

[0017] As mentioned above, shape memory materials can have the ability to change from one shape to another shape when the materials undergo a phase change. In some examples, the shape change can include changing the relative orientation of different portions of the material, such as by bending. In some cases, a shape memory material can have a “memory” or more permanent shape in one phase that the material “remembers.” Such materials can be deformed when the material is in a first phase and then return to the memory shape when the material transitions to a second phase. Some shape memory materials can remember two or more distinct shapes and reversibly transition between these shapes repeatedly by transitioning between different phases. Other shape memory materials may have a single memory shape and can be manually deformed into other temporary shapes, then returned to the memory shape through a phase transition. The shape memory composites described herein can utilize this property for a wide variety of applications. Potential uses for the shape memory composites can include morphological fitting together of components in a multi-component system, customizable thermal, electromagnetic interference (EMI), radio frequency interference (RFI), or shock remediation systems for electronic devices, and other uses.

[0018] Some applications may call for a shape memory component that can change shape to include transitioning from a flat shape to a sharp bend, such as a bend of 90 degrees or greater. Some shape memory materials may not be capable of forming such a sharp bend angle due to the phase transition of the shape memory material alone. Other situations that may be challenging for some shape memory materials can include designs involving multiple bends within a short distance of each other, curves having a small radius of curvature, and others. In such situations, a greater bend angle can be achieved by first performing the phase transition to cause the shape memory material to bend, and then applying additional force at the bend to increase the angle of the bend. The shape memory composites described herein can include a mechanochromic marking that can change color when the shape memory material bends initially, so that the location of the bend can be clearly observed optically. This can allow either a person to manually increase the bend angle or a machine to optically detect the location of the bend and then apply force to the correct location to increase the angle of the bend. Thus, the shape memory composites can be used for applications that involve sharper bend angles that may not be achievable by the phase transition of the shape memory material alone.

[0019] FIG. 1 shows an example shape memory composite 100 in accordance with one example of the present disclosure. The shape memory composite can include a shape memory material 110. In this example, the shape memory material is in the form of a flat sheet of shape memory material. The shape memory material can bend along fold regions 120 when the shape memory material transitions from a first phase to a second phase. In this example, the fold regions are shown as dashed lines along which the shape memory material bends. A mechanochromic marking 130 can be deposited on the surface of the shape memory material at the fold regions. In this example, the mechanochromic marking is shown as a shaded region that covers the fold regions. The mechanochromic marking can be formed by depositing a layer of mechanochromic material, such as a mechanochromic ink, in the area where bending will occur. Although the mechanochromic marking is shown as a shaded area in this example, in some cases the mechanochromic marking can be colorless until bending causes the mechanochromic marking to become colored, thereby making the fold region visible.

[0020] FIGs. 2A-2C show a perspective view of an example shape memory composite 200 in three states of bending. The shape memory composite includes a shape memory material 210 having fold regions 220 and a mechanochromic marking 230 on the surface of the shape memory material at the fold regions. In FIG. 2A, the shape memory composite as shown can be shaped as a flat sheet. The fold regions are shown as dashed lines to signify that the fold regions are not visible at this point. FIG. 2B shows the shape memory composite after the shape memory material has transitioned from a first phase to a second phase, causing the material to bend at the fold regions. In this figure, the fold regions are shown as solid lines to signify that the fold regions have become visible due to a color change of the mechanochromic marking along the fold regions. The mechanochromic marking can change color along the lines at which the shape memory material bends, while the rest of the mechanochromic marking can maintain the initial color or colorless state of the mechanophoric marking. This allows the bend line to be located precisely. FIG. 2C shows the shape memory composite after external force has been applied to increase the bend angles of the bends at each fold region. Thus, the final shape of the shape memory composite includes bend angles that are sharper than the bends achieved by the phase transition alone.

[0021] As used herein, “bend angle” refers to the angle between the initial orientation of the shape memory composite and the final orientation after the shape memory composite has bent. For example, a shape memory composite that begins as a flat piece of material and then bends to form a right angle shape can be referred to as a bend angle of 90 degrees. If additional force is applied to bend the material farther, then the bend angle can increase. For example, a 90 degree bend can be increased to a 120 degree bend by bending the material an additional 30 degrees. Likewise, and 180 degree bend angle can refer to the shape memory composite folding completely back on itself. In further examples, the shape memory composite may be bent in its initial state, and then during the phase transition the bend angle may change from its initial angle. In certain examples, a shape memory composite that is bent in its initial state can flatten partially or completely when the phase transition occurs. In any case, the bend angle can refer to the angle between the initial position of the material and the position following the phase transition and/or additional bending, whether the shape memory composite has an initially flat shape that bends or an initially bent shape that becomes flatter through the phase transition.

[0022] The shape memory material can have a variety of initial and final shapes. In some examples, the shape memory material can have the form of a flat sheet of material, as shown above. However, a variety of other forms can also be used, such as wires, tubes, or any other three-dimensional shape. Any of these shapes can undergo bending during a transition from a first phase to a second phase.

[0023] In further examples, the shape memory material can bend in a variety of different ways. In some examples, the shape memory material can bend along straight fold lines such as the fold regions shown in FIG. 1. In other examples, the shape memory material can bend along fold lines that are a compound of multiple smaller line segments. Various origami-like folding and unfolding structures can be formed using such straight-line folds. The shape memory material can also bend along curved fold regions in some cases. In other examples, the shape memory material can form more gradual curves as opposed to sharp angle bends. These and other shape changes can be used in combinations to form a wide variety of shapes. Some shape memory materials can also be capable of expanding or contracting in volume in response to a phase change, which can provide additional options for shape memory composites.

[0024] In various examples, the shape memory material can include a shape memory alloy, a shape memory polymer, or a combination thereof. Non-limiting examples of shape memory alloys can include nickel titanium, nickel titanium hafnium, nickel titanium palladium, nickel manganese gallium, nickel iron gallium, titanium niobium, cobalt nickel gallium, cobalt nickel aluminum, iron manganese silicon, manganese copper, iron platinum, copper zinc, copper zinc silicon, copper zinc aluminum, copper zinc tin, copper tin, copper aluminum nickel, and gold cadmium alloys. In certain examples, the shape memory material can be nitinol, an alloy of nickel and titanium. Shape memory polymers can include any polymers that can be deformed and return to a predetermined shape through the application of a stimulus. In various examples, the stimulus can include temperature, light, electricity, or the presence of a particular solvent. In certain examples, a shape memory polymer used in the shape memory composites described herein can be activated by a temperature change. Non-limiting examples of shape memory polymers can include polyurethanes, block copolymers that include blocks of polyethylene terephthalate and polyethyleneoxide, block copolymers that include blocks of polystyrene and poly(1,4-butadiene), block copolymers that include blocks of poly(2-methyl-2-oxazoline) and polytetrahydrofuran, polynorborene, polynorborene substituted with polyhedral oligosilsesquioxane, and other polymers that exhibit shape memory properties. In some examples, the shape memory polymer can be crosslinked using a crosslinker. In various examples the crosslinker may include glycerin, trimethylol propane, maleic anhydride, dimethyl-5-isophthalate, N,N'-methylen-bis-acrylamide, ethyleneglycol dimethacrylate, and others.

[0025] In certain examples, the shape memory material can bend in response to a phase transition from a first phase to a second phase, and then the bend can be reversible by a phase transition from the second phase back to the first phase. This can be accomplished, for example, using a shape memory alloy that has been trained to remember two different shapes or by a shape memory polymer that has been designed to remember two or more different shapes. In other examples, the bending of the shape memory material can be irreversible, in which case the shape memory composite can remain in the bent shape after the phase transition from the first phase to the second phase.

[0026] In some examples, the shape memory composite can include a single bend marked with a mechanophoric marking or multiple bends marked with mechanophoric markings. Furthermore, in some cases the shape memory composite can include bends that are not marked with a mechanophoric marking in addition to the bends that are marked with a mechanophoric marking. For example, if certain bends have smaller bend angles that are achievable by the phase transition of the shape memory material alone, then these bends may not be marked with a mechanophoric marking. Thus, mechanophoric markings can be deposited at bends that are to be bent farther after the phase transition, while no mechanochromic markings may be deposited on bends that can be achieved by the phase transition alone.

[0027] As used herein, “mechanochromic” refers to the property of exhibiting a color change in response to mechanical force. Mechanochromic materials can belong to a broader class of mechanophoric materials. “Mechanophoric” can refer to materials that react in any way to mechanical force, including by changing color and other reactions. Many mechanophoric materials include comparatively weak covalent bonds and/or non-covalent interactions that can be broken by the application of mechanical force. Examples of non-covalent interactions can include π-π interactions, metal-ligand interactions, and hydrogen bonding. Breaking of the bonds or interactions can result in a variety of effects, such as a color change. Other mechanisms may also be responsible for mechanophoric behavior. In some examples, the mechanochromic marking can include a mechanochromic polymer. Such polymers can include, for example, mechanoresponsive luminescent polymers. In other examples, the mechanochromic marking can include a mechanoresponsive luminescent molecular assembly. In certain examples, the mechanochromic marking can include a poly(diacetylene) polymer or a block copolymer including a poly(diacetylene) block. Additional examples of mechanochromic polymers can include poly(3-dodecylthiophene)s, poly(acetylene)s, poly(phenylene)s, poly(p-phenylene-vinylene)s, poly(pyrrole)s, poly(anthraquinone)s, and combinations thereof.

[0028] In various examples, the mechanochromic marking can change color in response to bending of the shape memory material. The color change can include any change in color that may be observable either by the human eye, machine vision, or other observation method. As used herein, “color change” can refer to a change from colorless to colored, a change from colored to colorless, a change from a first color to a second color, a change in color observable by infrared or ultraviolet sensor, a change in chroma, a change in saturation, a change in hue, a change in intensity, a change in chrominance, a change in density, and so on. The colors exhibited by the mechanochromic marking may be any visible, infrared, or ultraviolet color including black and white, and shades

[0029] In some examples, the mechanochromic markings described herein can be a layer of mechanochromic material. In certain examples, the mechanochromic material can be applied as a layer of mechanochromic ink. The mechanochromic ink can be coated onto the surface of the shape memory material using a variety of coating methods. In some cases, the mechanochromic ink can be printed using a digital printing method such as ink jet printing or laser jet printing.

[0030] As used herein, “ink jetting” or “jetting” refers to compositions that are ejected from jetting architecture, such as ink-jet architecture. Ink-jet architecture can include thermal or piezo architecture. Additionally, such architecture can print varying drop sizes such as less than 10 picoliters, less than 20 picoliters, less than 30 picoliters, less than 40 picoliters, less than 50 picoliters, etc.

[0031] In further examples, a mechanochromic ink can include a mechanochromic material as a colorant in an ink vehicle. As used herein, “ink vehicle” or “liquid vehicle” refers to a liquid fluid in which additives are placed to form inkjettable fluids, such as inks. A wide variety of liquid vehicles may be used in accordance with the technology of the present disclosure. Such liquid or ink vehicles may include a mixture of a variety of different agents, including, surfactants, solvents, co-solvents, anti-kogation agents, buffers, biocides, sequestering agents, viscosity modifiers, surface- active agents, water, etc. Though not part of the liquid vehicle *per se*, in addition to the mechanochromic colorants, the liquid vehicle can carry solid additives such as polymers, latexes, UV curable materials, plasticizers, salts, etc.

[0032] As mentioned above, the shape memory composites described herein can be used for a wide variety of applications. The field of custom manufacturing is an area in which the shape memory composites may be particularly useful. Custom manufacturing of goods is currently increasing in popularity, and will likely replace a portion of the market for mass produced goods. Mass production can involve maintaining large inventories of goods, global shipping of goods, and landfilling of goods when unwanted goods are produced but not sold. Thus, mass production can be inefficient and can negatively impact the environment. Custom manufacturing can be used on a smaller, more local scale to produce custom goods when and where the goods are wanted. This can reduce the inefficiencies and environmental costs compared to mass production. Additive manufacturing methods such as 3D printing are increasingly used to manufacture custom goods. These methods can be used to make goods quickly and with a small startup cost. In some cases 3D printing can also be used to make objects that would be impossible to make using traditional machining or molding techniques, such as objects having complex internal spaces formed as a single unitary piece.

[0033] The shape memory composites described herein can be used to more cheaply customize certain parts of custom manufactured goods that would otherwise be more expensive to design and manufacture. As an example, thermal management systems in electronic devices can often be costly to design. The high cost of designing thermal management systems can be offset by economies of scale when goods are mass produced. However, smaller scale custom manufacturing may not allow for these high costs to be recovered. The shape memory composites described herein can be used to enable more cheaply customizable thermal management systems in custom electronic devices. For example, a shape memory composite component can be designed to steer thermally conductive pathways into the correct locations within an electronic device to conduct heat from heat sources such as processors to heat sinks. In some cases, a thermally conductive shape memory material such as nickel titanium alloy can be used and shape memory material itself can be the thermally conductive pathway. In further examples, shape memory composites can be used to place other components into custom devices, such as EMI or RFI shielding materials or shock absorption materials. In some cases, auxetic materials (i.e., materials that are designed to increase in volume when the materials are placed in tension) can be fitted into place in a device using a shape memory composite, and the shape memory composite can also apply tension to the auxetic material to cause the auxetic material to expand in place.

[0034] FIG. 3 shows a cross-sectional view of an example multi-component system 300 in which a shape memory composite 302 is being inserted into an object 304. The object has multiple corners 340, 342, 344 around which the shape memory composite is to bend. In this example, the corners are located internally in the object and would be difficult to access without the use of the shape memory composite. The shape memory composite in this example has an initial bend 350. In some examples, this bend can be formed by phase transitioning a flat shape memory composite before inserting the shape memory composite into the object to create the bend, then reversing the phase transition and partially unbending the bend. In another example, the shape memory composite can be manufactured in this initial shape, having a bend at one end. The shape memory composite can be configured so that when the shape memory composite goes through a phase transition after insertion into the object, the bend can bend further around the corner 340.

[0035] FIG. 4 shows the multi-component system 300 after the shape memory composite 302 has undergone a phase transition from a first phase to a second phase. The phase transition resulted in the shape memory composite curving around the curving portion 360 of the object 304 and the initial bend 350 has bent further around the corner 340. The shape memory composite has also bent around corners 342 and 344. However, the phase transition alone did not cause the shape memory composite to bend at the desired bend angle to wrap around corners 342 and 344.

[0036] FIG. 5 shows the multi-component system 300 after the bends of the shape memory composite 302 proximate to corners 342 and 344 of the object 304 were bent farther by application of external force at the bends. The shape memory composite can include a mechanochromic marking (not shown) on a surface of the shape memory composite in the region of the bends. After the phase transition, the mechanochromic marking can show a visible color change along the bend lines. The visible line formed by this color change can be a guide to show where to apply the external force to the bends. Thus, the bend angles can be increased and the bends can wrap around corners 342 and 344. The object in this example has an opening allowing access to the bends near corners 342 and 344 so that the external force can be applied to the bends.

[0037] FIG. 6 shows a flowchart illustrating an example of the function of a shape memory composite 600 in accordance with an example of the present disclosure. The shape memory composite can include a shape memory material to bend along a fold region in response to a phase change in the shape memory material from a first phase to a second phase 610, and a mechanochromic marking deposited on a surface of the shape memory material at the fold region, wherein the mechanochromic marking changes color along the fold region in response to the bending of the shape memory material 620.

[0038] FIG. 7 shows a flowchart of an example method of making a multi-component system 700 in accordance with an example of the present disclosure. The method can include inserting a shape memory composite into a space within an object, the shape memory composite including a shape memory material and a mechanochromic marking deposited on a surface of the shape memory material at a fold region, the shape memory composite to bend along the fold region in response to a phase change in the shape memory material from a first phase to a second phase, wherein the object includes a corner located proximate to the shape memory composite when inserted 710; and changing a temperature of the shape memory material to cause the phase change in the shape memory material from the first phase to the second phase and bend along the fold region, wherein the mechanochromic marking changes color along the fold region in response to the bending of the shape memory material 720.

[0039] In further examples, an external force can be applied to the shape memory composite to bend the shape memory composite farther at the fold region. This can increase the bend angle to a desired bend angle around the corner of the object. In certain examples, the temperature of the shape memory composite can be changed while the shape memory composite is inserted into the object. For example, the shape memory composite can be fully or partially inserted and then the temperature of the shape memory composite can be changed. The temperature of the shape memory composite can also be changed concurrently with the motion of inserting the shape memory composite. In another example, the external force can also be applied to the shape memory composite while the shape memory composite is inserted in the object. In certain examples, a tool can be used to apply the external force to the shape memory composite. Such tools may include conduit benders, spikes, stakes, extraction tools, and so on.

[0040] Alternatively, the temperature of the shape memory composite can be changed before inserting the shape memory composite into the object. After the temperature is changed and the shape memory composite undergoes a phase transition to bend at the fold regions, an external force can be applied to the fold regions to increase the bend angle at the fold regions. The temperature of the shape memory composite can then be changed back to reverse the phase change. The bends can be partially unbent, and then the shape memory composite can be inserted into the object. After insertion, the phase change can be repeated to bend the shape memory composite at the fold regions again.

[0041]The shape memory composites described herein can be made with a wide variety of shapes and configured to bend in any useful way to assist in fitting into custom objects of any size and shape. Thus, the shape memory composites provide great flexibility in designing customized goods such as 3D printed devices with thermal management systems, EMI and RFI shielding, and many other various components that can be fitted into the devices using shape memory composites. Using mechanochromic markings to highlight fold regions as described herein can provide additional flexibility to design shape memory composites for applications where the phase transition may not be sufficient to create a sufficiently sharp bend angle.

[0042]It is noted that, as used in this specification and the appended claims, the singular forms ”a,” “an,” and “the” include plural referents unless the context clearly dictates otherwise.

[0043]As used herein, the term “substantial” or “substantially” when used in reference to a quantity or amount of a material, or a specific characteristic thereof, refers to an amount that is sufficient to provide an effect that the material or characteristic was intended to provide. The exact degree of deviation allowable may in some cases depend on the specific context.

[0044]As used herein, the term “about” is used to provide flexibility to a numerical range endpoint by providing that a given value may be “a little above” or “a little below” the endpoint. The degree of flexibility of this term can be dictated by the particular variable and determined based on the associated description herein.

[0045]As used herein, a plurality of items, structural elements, compositional elements, and/or materials may be presented in a common list for convenience. However, these lists should be construed as though each member of the list is individually identified as a separate and unique member. Thus, no individual member of such list should be construed as a de facto equivalent of any other member of the same list solely based on their presentation in a common group without indications to the contrary.

[0046] Concentrations, amounts, and other numerical data may be expressed or presented herein in a range format. It is to be understood that such a range format is used merely for convenience and brevity and thus should be interpreted flexibly to include not only the numerical values explicitly recited as the limits of the range, but also to include individual numerical values or sub-ranges encompassed within that range as if each numerical value and sub-range is explicitly recited. As an illustration, a numerical range of “about 1 wt% to about 5 wt%” should be interpreted to include not only the explicitly recited values of about 1 wt% to about 5 wt%, but also include individual values and sub-ranges within the indicated range. Thus, included in this numerical range are individual values such as 2, 3.5, and 4 and sub-ranges such as from 1-3, from 2-4, and from 3-5, etc. This same principle applies to ranges reciting only one numerical value. Furthermore, such an interpretation should apply regardless of the breadth of the range or the characteristics being described.

EXAMPLE

[0047] The following illustrates an example of the present disclosure. However, it is to be understood that the following is illustrative of the application of the principles of the present disclosure. Numerous modifications and alternative compositions, methods, and systems may be devised without departing from the spirit and scope of the present disclosure. The appended claims are intended to cover such modifications and arrangements.

[0048] A shape memory material sheet is formed of nickel titanium alloy (Nitinol) having the shape shown in FIG. 1. The shape memory material sheet is programmed to bend as shown in FIGs. 2A-2B. The shape memory material sheet is then flattened as shown in FIG. 1. A layer of mechanochromic ink containing a mechanochromic poly(diacetylene) is then printed in the area surrounding the fold regions as shown in FIG. 1 to form a shape memory composite. An electric current is applied to the shape memory composite to resistively heat the shape memory composite. When the shape memory composite reaches a threshold temperature, the shape memory material changes from a martensitic phase to an austenitic phase. When the phase changes, the shape memory composite bends as shown in FIG. 2B. The mechanochromic ink changes color along the fold lines in response to the bending motion. External force is then applied at the fold lines to further bend the shape memory composite into the shape shown in FIG. 2C.

CLAIMS

What is claimed is:

1. A shape memory composite, comprising:

a shape memory material to bend along a fold region in response to a phase change in the shape memory material from a first phase to a second phase; and

a mechanochromic marking deposited on a surface of the shape memory material at the fold region, wherein the mechanochromic marking changes color along the fold region in response to the bending of the shape memory material.

2. The shape memory composite of claim 1, wherein the shape memory material is in the form of a flat layer prior to the phase change from the first phase to the second phase.

3. The shape memory composite of claim 1, wherein the shape memory material comprises a shape memory alloy or a shape memory polymer.

4. The shape memory composite of claim 1, wherein the bending is reversible by a phase change in the shape memory material from the second phase back to the first phase.

5. The shape memory composite of claim 1, wherein the mechanochromic marking changes color such that the fold region becomes observable by:

a change from colorless to colored;

a change from colored to colorless;

a change from a first color to a second color; or

a change in color observable by an infrared or ultraviolet sensor.

6. The shape memory composite of claim 1, wherein the mechanochromic marking is a mechanochromic ink printed onto the shape memory material.

7. A multi-component system, comprising:

an object comprising a corner; and

a shape memory composite located proximate to the corner, wherein the shape memory composite comprises:

a shape memory material to bend along a fold region in response to a phase change in the shape memory material from a first phase to a second phase, wherein the shape memory material bends around the corner of the object, and

a mechanochromic marking deposited on a surface of the shape memory material at the fold region, wherein the mechanochromic marking changes color along the fold region in response to the bending of the shape memory material.

8. The system of claim 7, wherein the corner has an angle greater than a bend angle of the shape memory composite achieved by the bending of the shape memory composite in response to the phase change of the shape memory material alone.

9. The system of claim 8, wherein the shape memory composite has been bent farther at the fold region after the phase change by application of external force such that the bend angle is increased.

10. The system of claim 7, wherein the fold region is accessible when in place proximate to the corner of the object such that an external force can be applied to the fold region.

11. The system of claim 7, wherein the shape memory composite is a portion of a thermal management system, an electromagnetic interference remediation system, a radio frequency interference remediation system, an auxetic shock absorption system, or combination thereof.

12. A method of making a multi-component system, comprising:

inserting a shape memory composite into a space within an object, the shape memory composite including a shape memory material and a mechanochromic marking deposited on a surface of the shape memory material at a fold region, the shape memory composite to bend along the fold region in response to a phase change in the shape memory material from a first phase to a second phase, wherein the object comprises a corner located proximate to the shape memory composite when inserted; and

changing a temperature of the shape memory material to cause the phase change in the shape memory material from the first phase to the second phase and bend along the fold region, wherein the mechanochromic marking changes color along the fold region in response to the bending of the shape memory material.

13. The method of claim 12, further comprising applying an external force to the shape memory composite to bend farther at the fold region such that a bend angle of the shape memory composite is increased, and such that the shape memory composite bends around the corner of the object.

14. The method of claim 13, wherein changing of the temperature of the shape memory material and the applying external force to the shape memory composite are performed while the shape memory composite is inserted in the object.

15. The method of claim 13, wherein the changing of the temperature of the shape memory material and the applying external force to the shape memory composite are performed before inserting the shape memory composite into the object, and where the method further comprises reversing the phase change and partially unbending the bend in the shape memory material before inserting the shape memory composite into the object.

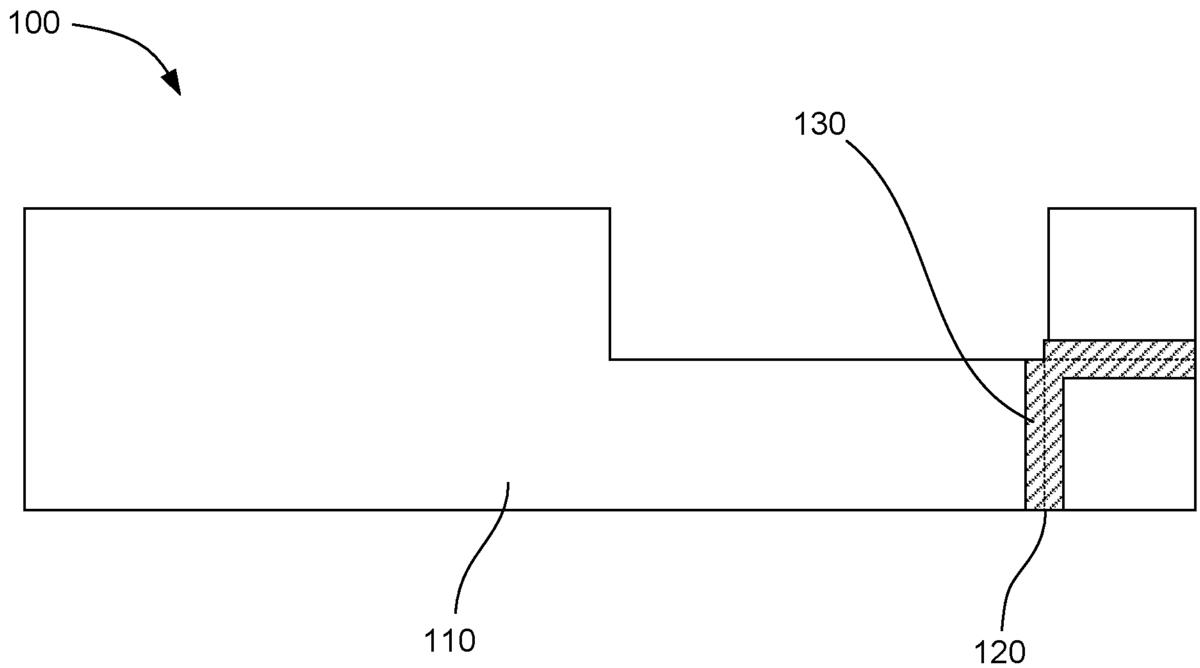

FIG. 1

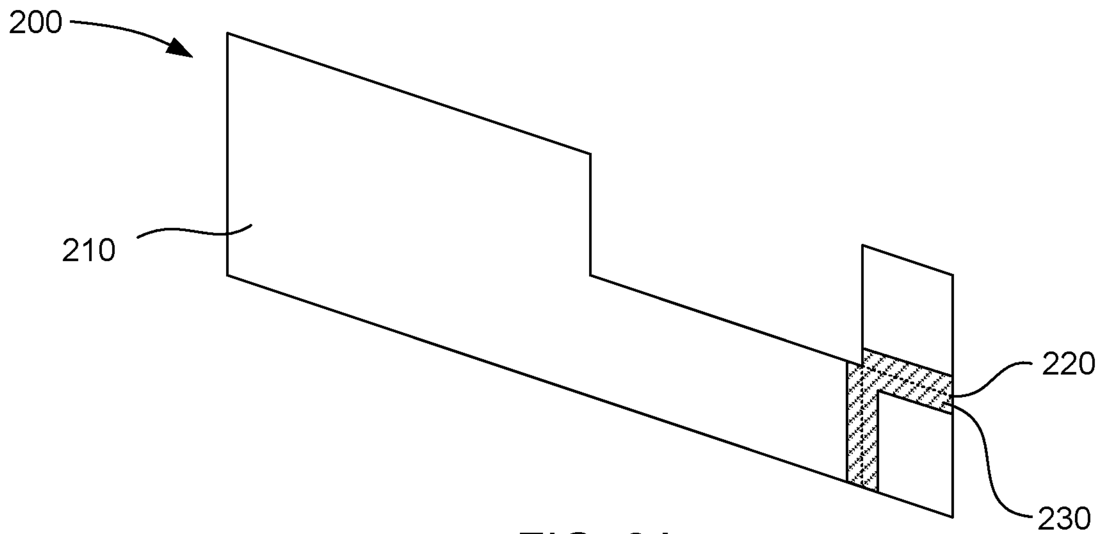

FIG. 2A

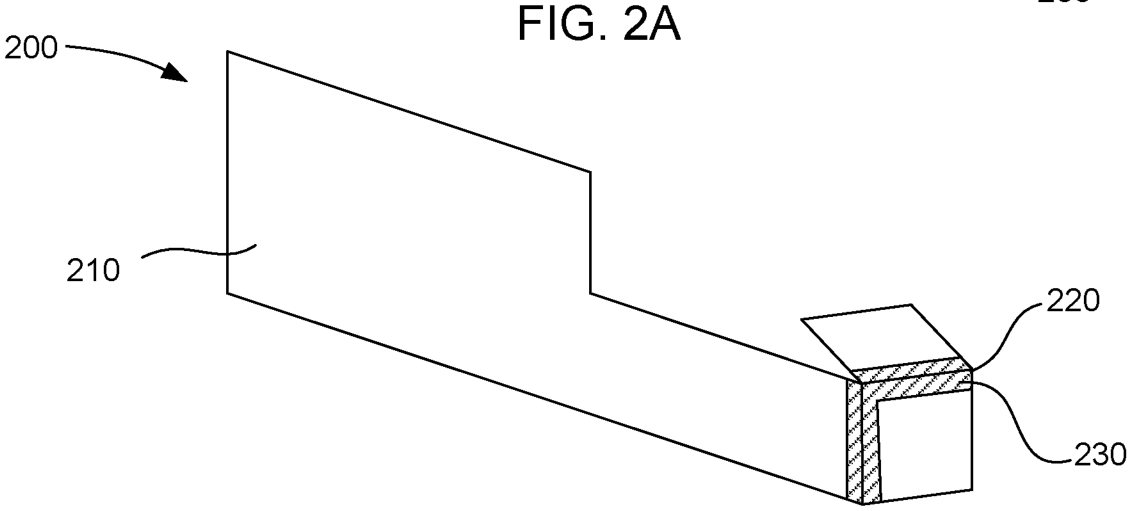

FIG. 2B

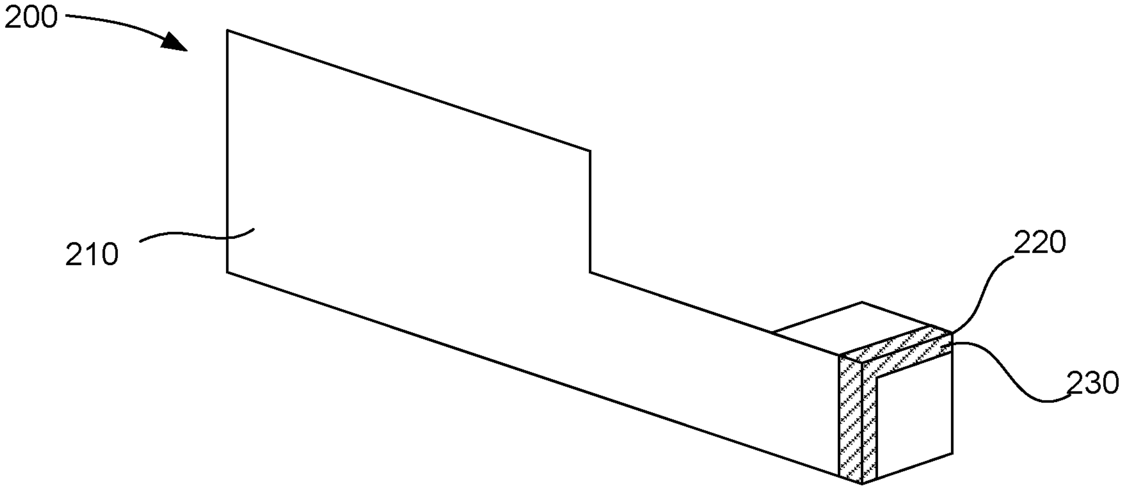

FIG. 2C

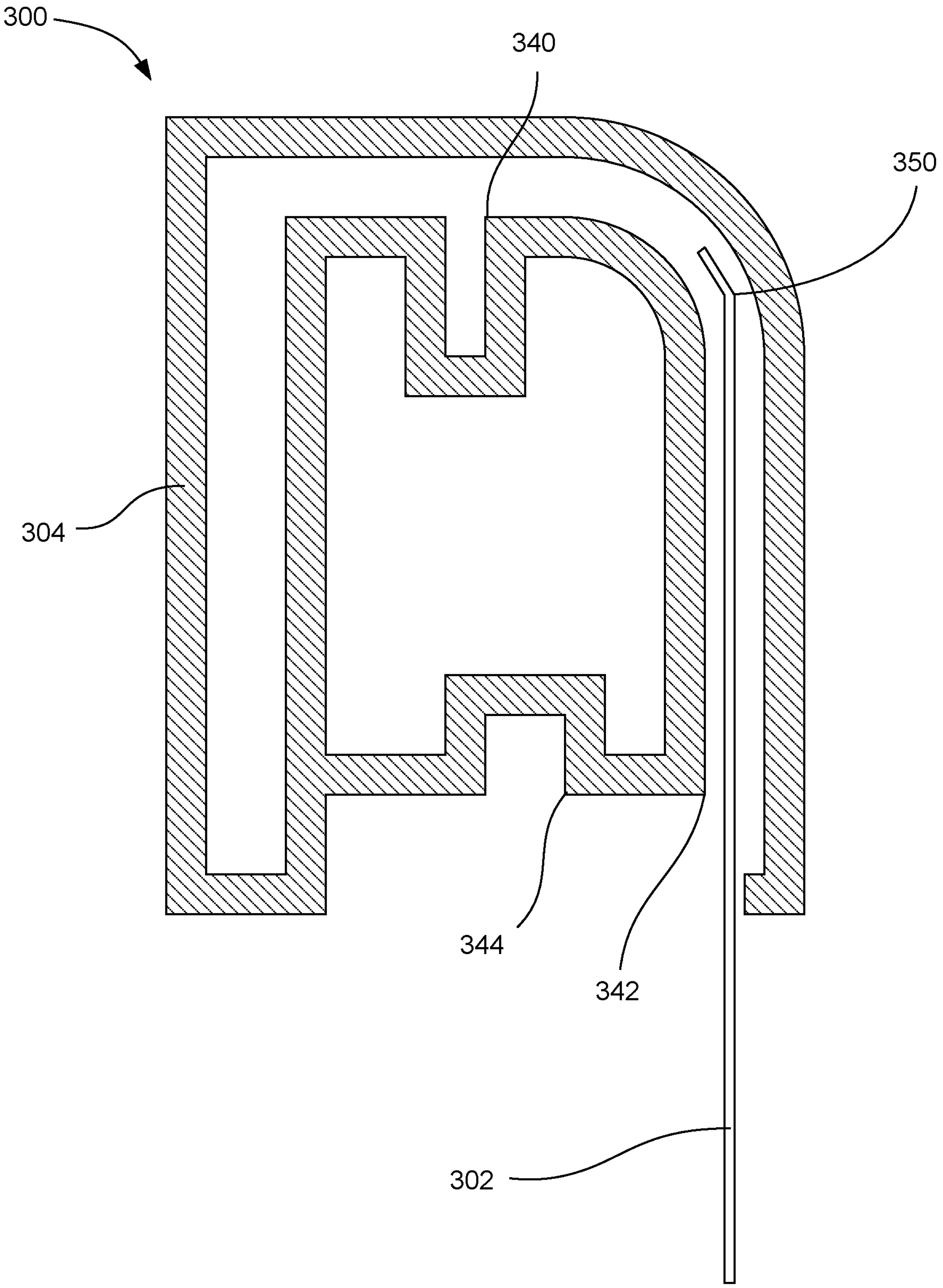

FIG. 3

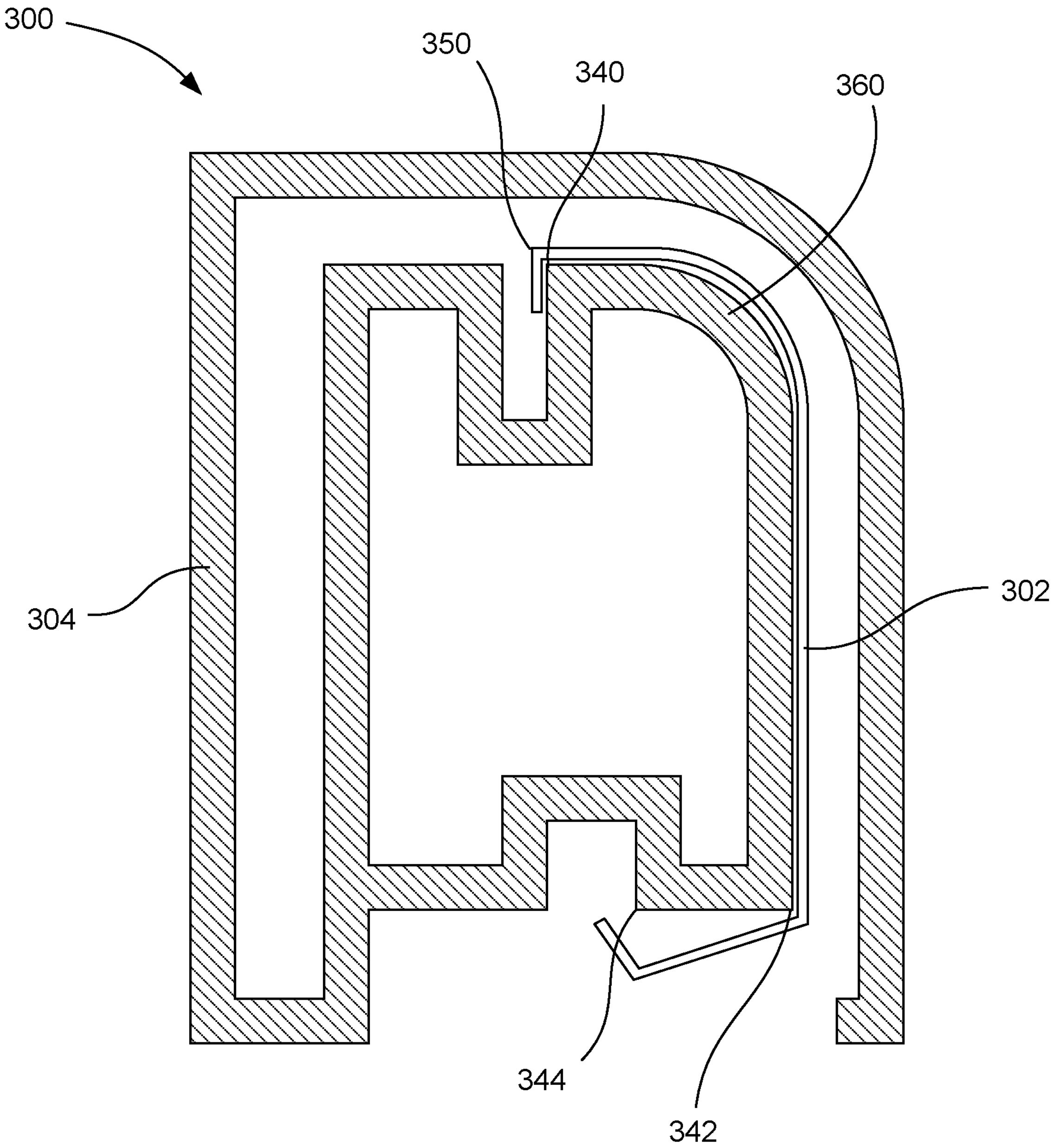

FIG. 4

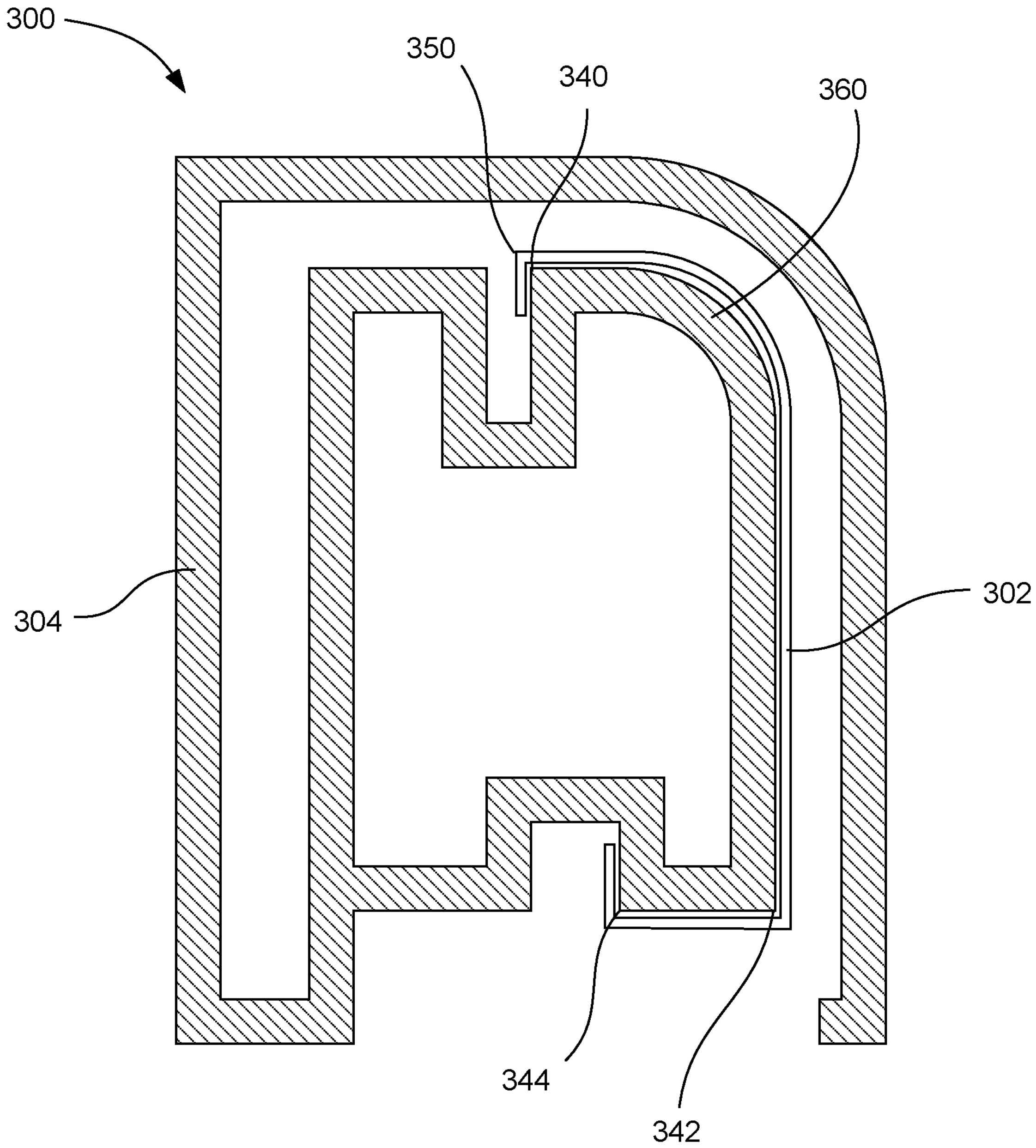

FIG. 5

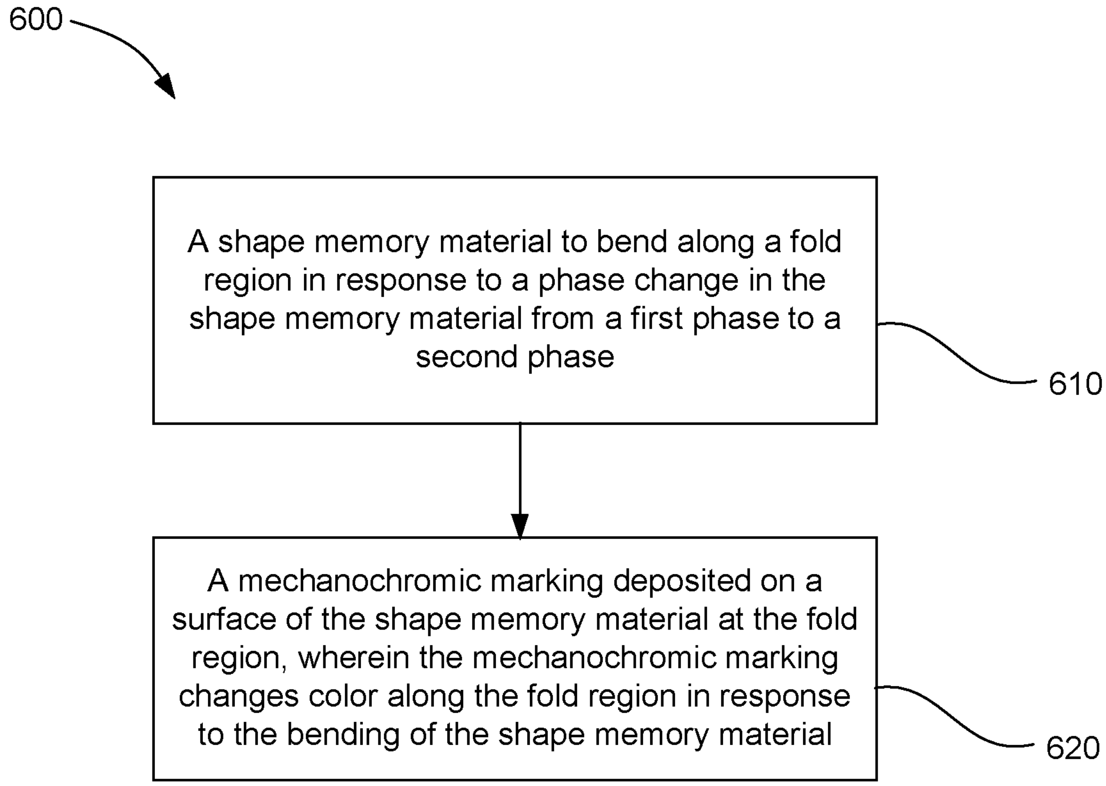
600
A shape memory material to bend along a fold region in response to a phase change in the shape memory material from a first phase to a second phase
610
A mechanochromic marking deposited on a surface of the shape memory material at the fold region, wherein the mechanochromic marking changes color along the fold region in response to the bending of the shape memory material
620

FIG. 6

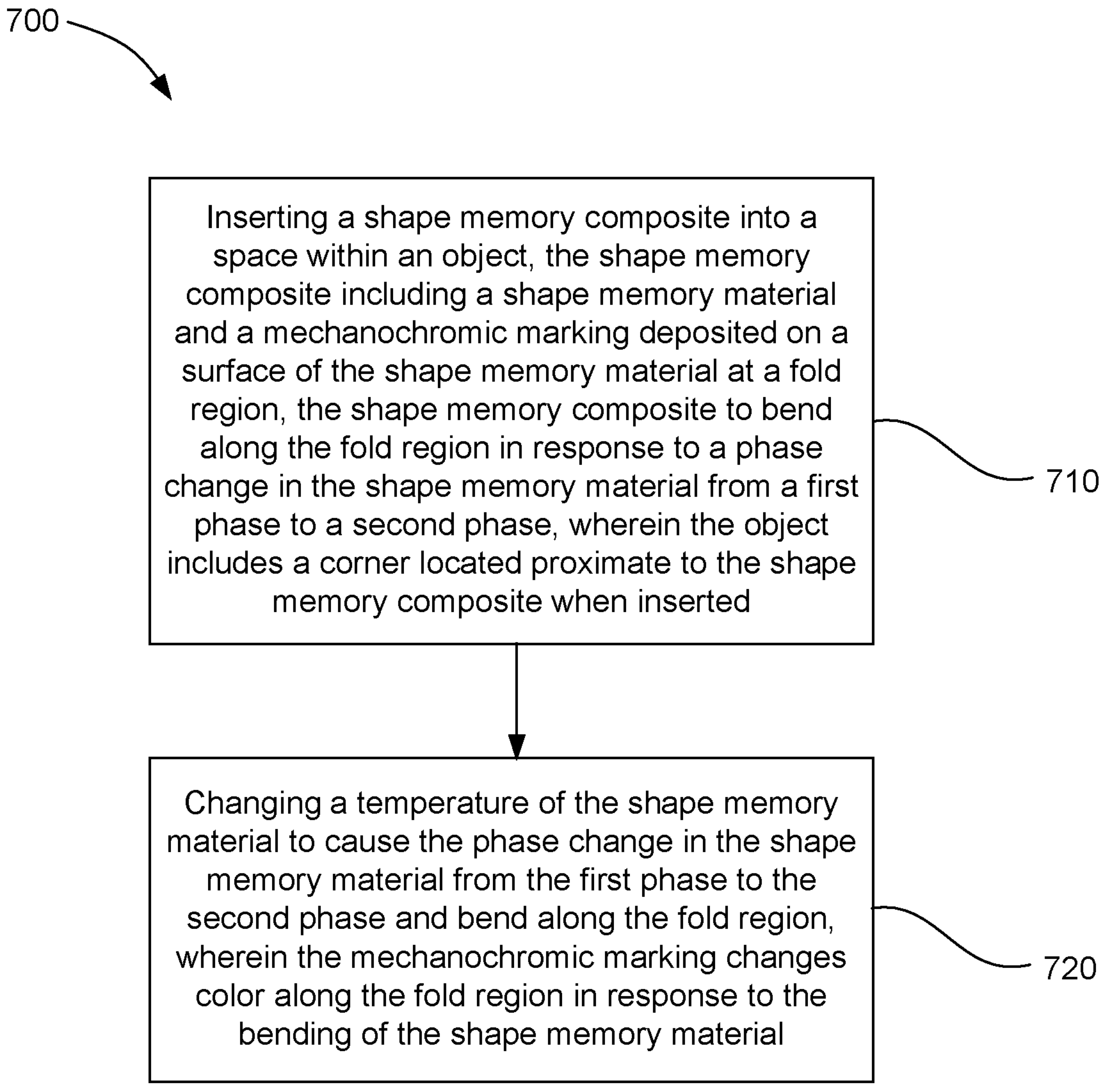
700
Inserting a shape memory composite into a space within an object, the shape memory composite including a shape memory material and a mechanochromic marking deposited on a surface of the shape memory material at a fold region, the shape memory composite to bend along the fold region in response to a phase change in the shape memory material from a first phase to a second phase, wherein the object includes a corner located proximate to the shape memory composite when inserted
710
Changing a temperature of the shape memory material to cause the phase change in the shape memory material from the first phase to the second phase and bend along the fold region, wherein the mechanochromic marking changes color along the fold region in response to the bending of the shape memory material
720

FIG. 7

INTERNATIONAL SEARCH REPORT	International application No. PCT/US 2018/017338

A. CLASSIFICATION OF SUBJECT MATTER

B29C 70/88 *(2006.01)*
C09K 3/00 *(2006.01)*
B29C 70/68 *(2006.0)*
H01R 4/01 (2006.01)

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)

B29C70/00-70/88, 67/00, H01R 4/00-4/72, C22F 1/00, G02F 1/01, G08F 20/00, A61F 2/82

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)

PatSearch (RUPTO internal), USPTO, PAJ, Esp@cenet, DWPI, EAPATIS, PATENTSCOPE

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	US 2013/0077148 A1 (SEGAN INDUSTRIES, INC.) 28.03.2013, claims 1-3,7,10,12,16, 18, paragraphs 0004-0006,0015, 0017-0019,0020, 0022,0026,0031,0032,0036,0041,0042,0046-0049,0050,0056,0061,0064, 0066, 0070,0084,0088,0115-0118,0190-0193	1-11 12-15
Y	WO 2007/099448 A2 (VAYRO LTD.) 07.09.2007, claims	12-15
A	US 2007/0259598 A1 (HANS O. RIBI) 08.11.2007	1-15

☐ 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 document 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	Date of mailing of the international search report
17 October 2018 (17.10.2018)	25 October 2018 (25.10.2018)
Name and mailing address of the ISA/RU: Federal Institute of Industrial Property, Berezhkovskaya nab., 30-1, Moscow, G-59, GSP-3, Russia, 125993 Facsimile No: (8-495) 531-63-18, (8-499) 243-33-37	Authorized officer A. Brazhnikova Telephone No. 8 499 240 25 91