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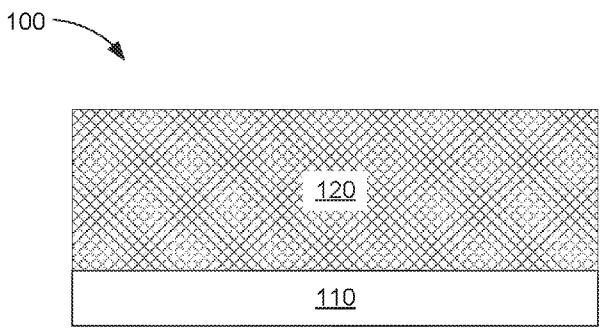


FIG. 1

(57) Abstract: The present disclosure is directed to multi-layered thermal insulating films "film" for electronic devices. The film can include a pressure-sensitive adhesive layer and a thermal insulating aerogel layer. The pressure-sensitive adhesive layer can include a pressure-sensitive adhesive. The thermal insulating aerogel layer can include an aerogel having a cross-linked silane coupling compound and a water-based polymer, wherein the silane coupling compound is halo-, oxygen-, or C1-C3 alkoxy-substituted. In some examples, the film can further include a polyethylene terephthalate film layer.

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# MULTI-LAYERED THERMAL INSULATING FILMS FOR ELECTRONIC DEVICES

## BACKGROUND

[0001] The use of electronic devices of all types continues to increase. Cellular phones, including smartphones, tablet computers, desktop computers, and laptop computers are used by many for personal, entertainment, and/or business purposes. Electronic devices have become a staple product in the lives of individuals. As the use of electronic devices continues to rise, so does the demand for components for electronic devices.

## BRIEF DESCRIPTION OF THE DRAWINGS

[0002] FIG. 1 graphically illustrates an example multi-layered thermal insulating film for an electronic device housing in accordance with the present disclosure;

[0003] FIG. 2 graphically illustrates an example multi-layered thermal insulating film for an electronic device housing in accordance with the present disclosure;

[0004] FIG. 3 graphically illustrates an example electronic device in accordance with the present disclosure; and

[0005] FIG. 4 is a flow diagram illustrating an example method of forming multi-layered thermal insulating film in accordance with the present disclosure.

## DETAILED DESCRIPTION

[0006] Electronic devices incorporate electronic components that generate heat during use as a byproduct of their use. Electronic devices may be prone to overheating due to direct, indirect, internal, and external influences. For example, small, portable electronic devices such as laptops and smartphones are prone to overheating because these smaller devices pack electronic components in small spaces which reduce heat transfer and thermal flow. In addition, environmental factors can contribute to overheating, such as weather conditions, temperature cycling, air flow blocking, improper use, and incompatible device use. Overheating can result in damage to the electronic device itself and/or objects surrounding said device. At the micro-level, overheating can cause material degradation that can result in cracks, expansion, structural deformation, and the like. At the macro-level, overheating can cause system failure, cause-effect loop, neighboring-effect, and the like. In addition, overheating can damage surrounding objects, cause fires, cause explosions, and cause injuries which can result in toasted skin syndrome, thermal burns, erythema, skin cancer, and so forth.

[0007] A multi-layered thermal insulating film "film" for an electronic device can include a pressure-sensitive adhesive layer including a pressure-sensitive adhesive, and a thermal insulating aerogel layer including an aerogel having a cross-linked silane coupling compound and a water-based polymer, wherein the silane coupling compound is halo-, oxygen-, or C1-C3 alkoxy-substituted. In an example, the pressure-sensitive adhesive can include a polymer selected from ethylene-vinyl acetate, polyimide, acrylic, silicone, polyurethane, styrene, styrene block copolymer, or a combination thereof. In another example, the silane coupling compound can be selected from $Si(OCH_3)_4$, $SiCl_4$, $K_2SiO_3$, or $Na_2SiO_3$ prior to cross-linking, and the water-based polymer can be selected from polyethyleneimine, polyvinyl alcohol, guar gum, gelatin, ethylene vinyl acetate, or a combination thereof. In yet another example, the aerogel can have a density from about 0.01 $g/cm^3$ to about 0.5 $g/cm^3$, a porosity from about 75 wt% to about 99 wt%, and a thermal conductivity from about 0.01 W/mk to about 0.03 W/mk. In a further example, the pressure-sensitive adhesive layer can have a thickness from about 2 μm to about 60

μm and the thermal insulating aerogel layer can have a thickness from about 50 μm to about 800 μm. In one example, the film can further include a polyethylene terephthalate film layer immediately adjacent to the pressure-sensitive adhesive layer. In another example, the polyethylene terephthalate film layer can be included as a release liner positioned on an opposite surface of the pressure-sensitive adhesive layer relative to the thermal insulating aerogel layer, or as a layer positioned between the pressure-sensitive adhesive layer and the thermal insulating aerogel layer, or both.

[0008] In another example, an electronic device can include a heat generating electronic component of an electronic device and a multi-layered thermal insulating film. The multi-layered thermal insulating film may be positioned on the heat generating electronic component. The multi-layered thermal insulating film can include a pressure-sensitive adhesive layer including a pressure-sensitive adhesive and a thermal insulating aerogel layer that can have an aerogel including a cross-linked silane coupling compound and a water-based polymer. The silane coupling compound can be halo-, oxygen-, or C1-C3 alkoxy-substituted. In an example, the multi-layered thermal insulating film can further include a polyethylene terephthalate film layer between the pressure-sensitive adhesive layer and the thermal insulating aerogel layer. The polyethylene terephthalate film layer can have a thickness from about 5 μm to about 100 μm. In another example, the multi-layered thermal insulating film can be located on an exterior of a housing of the electronic device, and the pressure-sensitive adhesive can adhere the multi-layered thermal insulating film to the housing. In yet another example, the heat generating electronic component can be selected from CPU, GPU, PCB, battery, memory, wireless charging device, or a combination thereof. In a further example, multi-layered thermal insulating film can be adhered to the heat generating electronic component.

[0009] Further presented herein is a method of forming a multi-layered thermal insulating film, such as for application to an electronic device. The method can include combining from about 15 wt% to about 40 wt% of a silane coupling compound and from about 0.5 wt% to about 85 wt% water to form a silicate-containing fluid; adjusting a pH of the silicate-containing fluid from a pH-adjusted silicon solution having a pH of about

pH 5 to about pH 8; admixing from about 10 wt% to about 30 wt% of a water-based polymer with from about 15 wt% to about 75 wt% of the pH-adjusted silicon solution to form an aerogel precursor fluid; baking the aerogel precursor fluid to a temperature ranging from about 80 °C to about 140 °C for a period of time from about 5 minutes to about 2 hours to form a thermal insulating aerogel layer including a crosslinked silane coupling compound and the water-based polymer wherein the silane coupling compound is halo-, oxygen-, or C1-C3 alkoxy-substituted. The method can further include adhering a pressure sensitive adhesive directly or indirectly to the thermal insulating aerogel layer to form the multi-layered thermal insulating film that includes the thermal insulating aerogel layer and a pressure-sensitive adhesive layer. In an example, the silane coupling compound can include alkali metal silicate, e.g., sodium silicate, potassium silicate, etc., and the adjusting can include lowering a pH of the silicate-containing fluid with an acid selected from sulfuric acid, nitric acid, tartaric acid, phosphoric acid, formic acid, acetic acid, or citric acid. In another example, the silane coupling compound can include silicon tetrachloride or tetramethyl orthosilicate and the adjusting can include raising a pH of the silicate-containing fluid with a base selected from potassium hydroxide, sodium hydroxide, barium hydroxide, calcium hydroxide, or magnesium hydroxide. In a further example, the method can further include applying a polyethylene terephthalate layer immediately adjacent to the pressure-sensitive adhesive. The polyethylene terephthalalate layer can be included as part of a release liner positioned on an opposite surface of the pressure-sensitive adhesive layer relative to where the thermal insulating aerogel layer is applied or is to be applied, as an intervening layer positioned between the pressure-sensitive adhesive layer and the thermal insulating aerogel layer, or both.

[0010] It is noted that when discussing the multi-layered thermal insulating film for an electronic device, the electronic device, and/or the method of forming the multi-layered thermal insulating film herein, these discussions can be considered applicable to one another whether or not they are explicitly discussed in the context of that example. Thus, for example, when discussing a thermal insulating aerogel layer related to the multi-layered thermal insulating film for an electronic device, such disclosure is

also relevant to and directly supported in the context of the electronic device, the method of forming the multi-layered thermal insulating film, and *vice versa*.

[0011] It is also understood that terms used herein will take on the ordinary meaning in the relevant technical field unless specified otherwise. In some instances, there are terms defined more specifically throughout the specification or included at the end of the present specification, and thus, these terms can have a meaning as described herein.

*Multi-Layered Thermal Insulating Films*

[0012] Multi-layered thermal insulating film 100 that can be applied to an electronic devices also referred to herein as "film(s)", and can include a pressure-sensitive adhesive layer 110 and a thermal insulating aerogel layer 120, as shown in FIG. 1. In yet other examples, the film can further include a polyethylene terephthalate film layer which can be located on a side of the pressure-sensitive adhesive layer opposite of the thermal insulating aerogel layer 130A, can be positioned between the thermal insulating aerogel layer and the pressure sensitive adhesive layer 130B, or a combination thereof. *See* FIG. 2.

[0013] The pressure-sensitive adhesive layer, in further detail, can include an adhesive layer operable to secure the film to the electronic device upon the application of pressure. The pressure sensitive adhesive can include a polymer. The polymer may be selected from ethylene-vinyl acetate, polyimide, acrylic, silicone, polyurethane, styrene, styrene block copolymer, or a combination thereof. In an example, the polymer may be selected from ethylene vinyl acetate, styrene, styrene block copolymer, acrylic, or a combination thereof. In another example, the polymer may be selected from polyimide, polyurethane, or a combination thereof. In yet another example, the polymer may be silicone. The pressure sensitive adhesive may be present as a pressure-sensitive adhesive layer that can have a thickness that can range from about 2 μm to about 60 μm, from about 5 μm to about 30 μm, from about 10 μm to about 30 μm, from about 20 μm to about 40 μm, from about 30 μm to about 50 μm, from about 40 μm to about 60 μm, or from about 15 μm to about 25 μm.

[0014] The film can further include a thermal insulating aerogel layer. The thermal insulating aerogel layer can include an aerogel and that can allow for heat transfer and thermal flow therethrough. Aerogels can be synthetic porous ultralight materials in which a liquid component has been replaced with gas without a significant collapse in a gel structure of the aerogel. The aerogel presented herein can have a porosity that can range from about 75% to about 99%, from about 80 wt% to about 90 wt%, from about 75 wt% to about 95 wt%, from about 90% to about 99%, or from about 85% to about 95%. A density of the aerogel can range from about 0.01 g/cm$^3$ to about 0.5 g/cm$^3$, from about 0.1 g/cm$^3$ to about 0.5 g/cm$^3$, from about 0.01 g/cm$^3$ to about 0.1 g/cm$^3$, or from about 0.05 g/cm$^3$ to about 0.3 g/cm$^3$. The porous and light nature of the aerogel can allow for heat transfer and thermal flow. A thermal conductivity of the aerogel can range from about 0.01 W/mK to about 0.03 W/mK, from about 0.01 W/mk to about 0.02 W/mk, or from about 0.02 W/mk to about 0.03 W/mk. The aerogel can exhibit thermal insulative properties.

[0015] The aerogel of the thermal insulating aerogel layer can include a silane coupling compound and a water-based polymer. The silane coupling compound, prior to cross-linking, may be selected from $Si(OCH_3)_4$, $SiCl_4$, $K_2SiO_3$, $Na_2SiO_3$, or a combination thereof. In an example, prior to cross-linking, the silane coupling compound may be a silicate. The silicate can be selected from $Si(OCH_3)_4$, $K_2SiO_3$, $Na_2SiO_3$, or a combination thereof. In yet other examples, the silane coupling compound, prior to cross-linking, can be selected from $Si(OCH_3)_4$, $Na_2SiO_3$, or a combination thereof. The silane coupling compound in a further example, prior to cross-linking, can include $Na_2SiO_3$. The silane coupling compound can cross-link with a water-based polymer.

[0016] Water-based polymer, as used herein, refers to a polymer that uses water as a carrying medium and can include waterborne resins that can be water soluble, water-reducible, or water dispersed. In some examples, water can be one of the monomers used to form the water-based polymer. In other examples, the water-based polymer can be configured to hold water before drying and/or evaporation therefrom. The water-based polymer, prior to cross-linking, can include polyethyleneimine, polyvinyl alcohol, guar gum, gelatin, ethylene vinyl acetate, or a combination thereof. In

another example, the water-based polymer, prior to cross-linking, can include, polyethyleneimine, gelatin, ethylene vinyl acetate, or a combination thereof. In yet another example, the water-based polymer, prior to cross-linking, can include polyvinyl alcohol, guar gum, or a combination thereof. In a further example, the water-based polymer, prior to cross-linking, can include polyethyleneimine, polyvinyl alcohol, or a combination thereof. The water-based polymer can be present at from about 25 wt% to about 70 wt%, from about 30 wt% to about 60 wt%, from about 25 wt% to about 50 wt%, or from about 50 wt% to about 70 wt%.

[0017] The silane coupling compound and the water-based polymer can interact with one another and cross-link. In one example, an interaction can occur through a catalyzed hydrolysis and a condensation reaction. For example, when silicate and polyvinyl alcohol interact, hydrolization can occur releasing the hydroxyl groups on the polyvinyl alcohol. Carbon from the hydroxyl group released therefrom and the silanol of the silicate can interact and form a Si-O-C bond. In yet another example, tetraethyl orthosilicate can undergo a hydrolysis-condensation reaction to form a nano-$SiO_2$ which can become dispersed in a polymer matrix of the water-based polymer. The silane coupling compound can be present at from about 30 wt% to about 75 wt%, from about 40 wt% to about 60 wt%, from about 30 wt% to about 50 wt%, or from about 50 wt% to about 75 wt%.

[0018] Following an interaction between the silane coupling compound and the water-based polymer, water and other liquids therein can be removed through evaporation and the thermal insulative aerogel can be formed. The thermal insulative aerogel can be stronger and more robust than silica aerogels that do not include a water-based polymer. Silica aerogels that do not include a water-based polymer can be weak and brittle in nature. Without being limited to theory, it is speculated that the increased durability may be due to cross-linking of the silane coupling compound and the water-based polymer.

[0019] The aerogel can be present as a thermal insulating aerogel layer in the multi-layered thermal insulating film. The thermal insulating aerogel layer can have a thickness that can range from about 50 μm to about 800 μm, from about 50 μm to about

500 μm, from about 50 μm to about 250 μm, from about 100 μm to about 500 μm, from about 250 μm to about 750 μm, from about 300 μm to about 600 μm, or from about 400 μm to about 800 μm.

[0020] In some examples, the multi-layered thermal insulating film can further include a polyethylene terephthalate film layer. The polyethylene terephthalate film layer can include polyethylene terephthalate and can be immediately adjacent to the pressure-sensitive adhesive layer. The polyethylene terephthalate film layer may act as a release liner positioned on an opposite surface of the pressure-sensitive adhesive layer relative to the thermal insulating aerogel layer, or as a layer positioned between the pressure-sensitive adhesive layer and the thermal insulating aerogel layer, or can be positioned on both sides of the pressure-sensitive adhesive layer.

[0021] In one example, the polyethylene terephthalate can be a release liner positioned on an opposite surface of the pressure-sensitive adhesive layer from the thermal insulating aerogel layer. The release liner can have a thickness that can range from about 15 μm to about 75 μm, from about 20 μm to about 60 μm, from about 15 μm to about 30 μm, from about 30 μm to about 60 μm, from about 25 μm to about 75 μm, or from about 50 μm to about 75 μm. A polyethylene terephthalate film layer that can form and act as a release liner can be a removable liner, which may be removed to expose the pressure-sensitive adhesive layer and allow the pressure-sensitive adhesive layer to be adhered to an electronic device or an electronic component of an electronic device.

[0022] In another example, the polyethylene terephthalate can be positioned as a layer between the pressure-sensitive adhesive layer and the thermal insulating aerogel layer. This layer can be operable as a support or carrier that can provide strength to the film. The polyethylene terephthalate layer positioned between the pressure-sensitive adhesive layer and the thermal insulating aerogel layer can have a thickness that can range from about 5 μm to about 100 μm, from about 10 μm to about 60 μm, from about 5 μm to about 50 μm, from about 25 μm to about 50 μm, from about 25 μm to about 75 μm, from about 50 μm to about 75 μm, or from about 50 μm to about 90 μm.

[0023] The multi-layered thermal insulating film can have a total thickness that can range from about 50 μm to about 1 mm, from about 100 μm to about 600 μm, from

about 150 μm to about 650 μm, from about 500 μm to 1 mm, from about 750 μm to about 1 mm, from about 50 μm to about 250 μm, from about 50 μm to about 500 μm, from about 250 μm to about 500 μm, from about 300 μm to about 600 μm, or from about 400 μm to about 800 μm.

*Electronic Devices*

[0024] Further presented herein is an electronic device. The electronic device 300, in further detail, can include a heat generating electronic 310 and a multi-layered thermal insulating film 100 positioned on the heat generating electronic component. *See* FIG. 3. The film can include a pressure-sensitive adhesive layer 110 and a thermal insulating aerogel layer 120. The pressure-sensitive adhesive layer can include a pressure-sensitive adhesive. The thermal insulating aerogel layer can include an aerogel having a cross-linked silane coupling compound and a water-based polymer. In some examples, the multi-layered thermal insulating film can further include a polyethylene terephthalate film layer. The film, the pressure sensitive adhesive layer, the thermal insulating aerogel layer, the polyethylene terephthalate film layer if present, or the combination thereof can be as described above.

[0025] The electronic component, in further detail, can include any heat generating electric component of any electrical device. In some examples, the electronic component can include heat generating components of a laptop, a desktop, a smartphone, a tablet, a printer, a monitor, a keyboard, headphones, a television, a speaker, a docking station, a webcam, a smart watch, a calculator, or the like. For example, the heat generating component can include a CPU, GPU, PCB, battery, memory, wireless charging device, or a combination thereof. In on example, the heat generating electronic component can include a CPU. In another example, the heat generating electronic component can include a GPU. The electronic device, likewise may include a laptop, a desktop, a smartphone, a tablet, a printer, a monitor, a keyboard, headphones, a television, a speaker, a docking station, a webcam, a smart watch, a calculator, or a combination thereof.

[0026] The multi-layered thermal insulating film may be positioned on the heat generating electronic component, or may be positioned over the heat generating electronic component with intervening materials therebetween. For example, the multi-layered thermal insulating film may be located directly on top of the CPU, GPU, PCB, battery, memory, wireless charging device, or a combination thereof, with the pressure-sensitive adhesive layer directly positioned on the CPU, GPU, PCB, battery, memory, wireless charging device, or a combination thereof. In yet other examples, the multi-layered thermal insulating film may be located on an exterior of a housing of the electronic device with the pressure-sensitive adhesive layer being positioned directly on and adhering the multi-layered thermal insulating film to the housing.

[0027] The incorporation of the multi-layered thermal insulating film in or on an electronic device can reduce an amount of heat passing from the heat generating electronic component to other electrical components of the electronic device, or can reduce an amount of heat existing in the electronic device. For example, a temperature of the electronic device can be from about 1 °C to about 3 °C or from about 1.5 °C to about 2.5 °C cooler than a temperature of the same electronic device, under the same operating conditions, without the multi-layered thermal insulating film. Accordingly, incorporating the multi-layered thermal insulating film can reduce or eliminate potential damage to the electronic device itself and objects surrounding said device. Accordingly, the multi-layered thermal insulating film can reduce or minimize an occurrence of cracks, expansion, structural deformations, system failure, cause-effect loop, neighboring-effect, battery explosions, and the like. In addition, the multi-layered thermal insulating film can reduce or minimize an occurrence of damage to surrounding objects, the user, and the like. The incorporation of the multi-layered thermal insulating film can also improve information loading speed, power efficiency, and the overall lifetime of the electronic device.

*Methods of Forming a Multi-Layered Thermal Insulating Films*

[0028] A flow diagram of an example method 400 of forming a multi-layered thermal insulating film for an electronic device is shown in FIG. 4. The method can

include combining 410 from about 15 wt% to about 40 wt% of a silane coupling compound and from about 60 wt% to about 85 wt% water to form a silane coupling fluid, adjusting 420 a pH of the silane coupling fluid to form a pH-adjusted silane coupling fluid having a pH of about pH 5 to about pH 8, admixing 430 from about 10 wt% to about 30 wt% of a water-based polymer with from about 15 wt% to about 75 wt% of the pH-adjusted silane coupling fluid to form an aerogel precursor fluid, baking 440 the aerogel precursor fluid to a temperature ranging from about 80 °C to about 140 °C for a period of time from about 15 minutes to about 1 hour to form a thermal insulating aerogel layer including a crosslinked silane coupling compound and the water-based polymer, and adhering 450 a pressure sensitive adhesive directly or indirectly to the thermal insulating aerogel layer to form the multi-layered thermal insulating film that includes the thermal insulating aerogel layer and a pressure-sensitive adhesive layer.

[0029] The combining, in further detail, can include admixing from about 15 wt% to about 40 wt% of a silane coupling compound, with from about 0.5 wt% to about 85 wt% water, and/or from about 0 wt% to about 85 wt% organic cosolvent to form a silane coupling fluid. In some examples, the silane coupling compound may be present from about 15 wt% to about 30 wt%, from about 20 wt% to about 40 wt%, from about 25 wt% to about 35 wt%, or from about 30 wt% to about 40 wt% in the silane coupling fluid. Water can be present to balance.

[0030] In some examples, in addition to the water, the silane coupling compound can also be dispersed in a liquid vehicle that includes organic cosolvent or other liquid components as well. For example, the silane coupling compound may be dispersed or dissolved in the water and/or organic cosolvent. The water can be present at from about 0.5 wt% to about 85 wt%, from about 0.5 wt% to about 50 wt%, from about 25 wt% to about 75 wt%, or from about 6 wt% to about 85 wt%. The water may be deionized. The organic cosolvent, if present, can be included at from about 0.1 wt% to about 85 wt%, from about 1 wt% to about 60 wt%, or from about 5 wt% to about 50 wt%, for example. Furthermore, the organic cosolvent can include, for example, a polyol, a diol, an oligoglycol, a lactam or a combination thereof. For example, the organic cosolvent can be selected from diols such as; 1,2 butanediol; 1,2-propanediol; 2,3-butanediol; 1,2-

pentanediol; 2-methyl-2,4-pentanediol; 2-methyl-1,3-propanediol; triols; tetrahydrofuran; ethylene glycol dimethyl ether; ethylene glycol diethylene glycol; triethylene glycol; propylene glycol; tripropylene glycol butyl ether; lactams; 2-pyrrolidone; 1-(2-hydroxyl)-2-pyrrolidone; or a combination thereof. In another example, a cosolvent can be a diol and the diol can be selected from 1,2 butanediol; 1,2-propanediol; 2,3-butanediol; 1,2-pentanediol; 2-methyl-2,4-pentanediol; 2-methyl-1,3-propanediol; or a combination thereof. In yet another example, a cosolvent can be 1,2 butanediol.

[0031] A pH of the silane coupling fluid can be adjusted to a pH ranging from about 5 to a pH of about 8. In yet other examples, the pH can be adjusted to a pH ranging from about 5 to a pH of about 7, from a pH of about 6 to a pH of about 8, or from a pH of about 7 to a pH of about 8. The adjusting may be dependent upon an initial pH of the silane coupling fluid. In some examples, adjusting a pH can include lowering a pH of the silane coupling fluid. The lowering can occur by the addition of an acid to the silane coupling fluid. The acid, in some examples, may be selected from sulfuric acid, nitric acid, tartaric acid, phosphoric acid, formic acid, acetic acid, or citric acid. For example, the silane coupling compound can include alkali metal silicate, e.g., sodium silicate, potassium silicate, etc., and the adjusting can include lowering a pH of the silane coupling fluid to a pH of about 5 to about 7 with an acid. In another example, adjusting a pH can include raising a pH of the silane coupling fluid. Raising the pH can occur by the addition of a base to the silane coupling fluid. The base, in some examples, may be selected from potassium hydroxide, sodium hydroxide, barium hydroxide, calcium hydroxide, or magnesium hydroxide. For example, the silane coupling compound can include silicon tetrachloride or tetramethyl orthosilicate and the adjusting can include raising a pH of the silane coupling fluid with a base. The adjusting may occur while heating to a temperature that can range from about 20 °C to about 60 °C or from about 30 °C to about 50 °C for a time period ranging from about 5 minutes to about 15 minutes.

[0032] Following the pH adjustment, from about 15 wt% to about 75 wt% of the pH-adjusted silane coupling fluid can be admixed with from about 10 wt% to about 30 wt% of a water-based polymer to form an aerogel precursor fluid. In yet other examples,

the admixing can include admixing from about 15 wt% to about 30 wt% of a water-based polymer with from about 20 wt% to about 70 wt% of the pH-adjusted silane coupling fluid or from about 20 wt% to about 30 wt% of a water-based polymer with from about 30 wt% to about 70 wt% of the pH-adjusted silane coupling fluid. The admixing may occur with a magnetic stir rod for a period of time that can range from about 30 minutes to about 60 minutes.

[0033] The aerogel precursor fluid can be baked to remove the liquid component therefrom and replace the liquid component with gas without causing a significant collapse in the gel structure of the aerogel precursor fluid, thereby forming a crosslinked silane coupling compound and water-based polymer. The baking, in further detail, can occur at a temperature that can range from about 80 °C to about 140 °C for a period of time that can range from about 5 minutes to about 2 hours. In some examples, the temperature can range from about 100 °C to about 120 °C, from about 80 °C to about 120 °C, or from about 100 °C to about 140 °C. The baking can occur under atmospheric conditions. The period of time, in some examples, can range from about 15 minutes to about 30 minutes, from about 5 minutes to about 60 minutes, from about 60 minutes to about 120 minutes, or from about 5 minutes to about 45 minutes.

[0034] Adhering a pressure sensitive adhesive directly or indirectly to the thermal insulating aerogel layer can occur by dipping, ejecting, electrical deposition, or thermal printing of the pressure-sensitive adhesive. Dipping can include submerging a surface into the pressure sensitive adhesive. Ejecting can involve blowing droplets of the pressure sensitive adhesive from a fluid ejector onto a surface. The fluid ejector can have a flow rate that can range from about 5 gpm to about 60 gpm and can have a pressure ranging from about 15 psi to about 60 psi. A surface that the pressure sensitive adhesive can be applied to can vary depending on a configuration of the multi-layered thermal insulating film formed.

[0035] When the multi-layered thermal insulating film formed has a pressure-sensitive adhesive layer and a thermal insulating layer and excludes a polyethylene terephthalate film layer, then the pressure sensitive adhesive can be applied directly to the thermal insulating aerogel layer including a crosslinked silane coupling compound

and the water-based polymer. When a polyethylene terephthalate film layer is present, then the multi-layered thermal insulating film can be assembled as described below.

[0036] When a polyethylene terephthalate film layer is present or to be present and situated between the pressure sensitive adhesive layer and the thermal insulating aerogel layer of the multi-layered thermal insulating film, then the aerogel precursor fluid can be applied over the polyethylene terephthalate film layer and liquid from the aerogel precursor fluid can be removed through baking. The baking can occur at a temperature ranging from about 80 °C to about 140 °C for a period of time from about 5 minutes to about 2 hours, or more typically from about 15 minutes to about 60 minutes, to form a thermal insulating aerogel layer including a crosslinked silane coupling compound and the water-based polymer on the polyethylene terephthalate film. Then the pressure-sensitive adhesive layer can be applied to an opposite surface of the polyethylene terephthalate film from a surface of the polyethylene terephthalate film with the thermal insulating aerogel layer thereon. The film can then be adhesion baked at a temperature that can range from about 50 °C to about 90 °C for a period of time that can range from about 3 minutes to about 20 minutes.

[0037] When the polyethylene terephthalate film is present or to be present as a release liner and a polyethylene terephthalate film is not present as a layer positioned between the pressure-sensitive adhesive layer and the thermal insulating aerogel layer, then the pressure-sensitive adhesive layer can be applied to a surface of the polyethylene terephthalate film. In some examples, the polyethylene terephthalate with the pressure sensitive adhesive thereon may be adhesion baked at a temperature that can range from about 50 °C to about 90 °C for a period of time from about 3 minutes to about 20 minutes. Then a surface of the pressure sensitive adhesive opposite of the surface of the pressure-sensitive adhesive adjacent to the polyethylene terephthalate film can have the aerogel precursor fluid applied thereto. Then the polyethylene terephthalate film, the pressure-sensitive adhesive, and the aerogel precursor fluid can be baked to a temperature that can range from about 80 °C to about 140 °C for a period of time that can range from about 5 minutes to about 2 hours, or more typically from

about 15 minutes to about 60 minutes, to form a thermal insulating aerogel layer including a crosslinked silane coupling compound and the water-based polymer.

[0038] When a polyethylene terephthalate film is present or to be present as a release liner and as a layer positioned between the pressure-sensitive adhesive layer and the thermal insulating aerogel layer, then a layer of the polyethylene terephthalate film can have the aerogel precursor fluid applied thereto. The polyethylene terephthalate film with the aerogel precursor fluid thereon can be baked to a temperature that can range from about 80 °C to about 140 °C for a period of time that can range from about 5 minutes to about 2 hours, or more typically from about 15 minutes to about 60 minutes, to form a thermal insulating aerogel layer including a crosslinked silane coupling compound and the water-based polymer positioned on a polyethylene terephthalate film. A pressure-sensitive adhesive can be applied to a surface of the polyethylene terephthalate film opposite of the surface of the polyethylene terephthalate film having the crosslinked silane coupling compound and the water-based polymer. The layers can be adhesion baked at a temperature that can range from about 50 °C to about 90 °C for a period of time that can range from about 3 minutes to about 20 minutes. A release liner of polyethylene terephthalate film can then be applied to an exposed surface of the pressure-sensitive adhesive layer.

[0039] Alternatively, when a polyethylene terephthalate film is present or to be present as a release liner and as a layer positioned between the pressure-sensitive adhesive layer and the thermal insulating aerogel layer, then the pressure-sensitive adhesive layer can be applied to a surface of the polyethylene terephthalate film. A second polyethylene terephthalate film can be applied to an opposite surface of the pressure-sensitive adhesive layer, sandwiching the pressure-sensitive adhesive layer between two layers of the polyethylene terephthalate film. Then the aerogel precursor fluid can be applied to an exposed surface of one of the polyethylene terephthalate film layers and all of the layers can be baked to a temperature that can range from about 80 °C to about 140 °C for a period of time that can range from about 5 minutes to about 2 hours, or more typically from about 15 minutes to about 60 minutes, to form a thermal insulating aerogel layer including a crosslinked silane coupling compound and the

water-based polymer and to adhesion bake the pressure-sensitive adhesive to the polyethylene terephthalate film layers.

*Definitions*

[0040] As used in this specification and the appended claims, the singular forms "a," "an," and "the" include plural referents unless the content clearly dictates otherwise.

[0041] The term "about" as used herein, when referring to a numerical value or range, allows for a degree of variability in the value or range, for example, within 10%, or, in one aspect within 5%, of a stated value or of a stated limit of a range. The term "about" when modifying a numerical range includes as one numerical subrange a range defined by the exact numerical value indicated, e.g., the range of about 1 wt% to about 5 wt% includes 1 wt% to 5 wt% as an explicitly supported sub-range.

[0042] 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 the individual member of the list is also 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 based on presentation in a common group without indications to the contrary.

[0043] Concentrations, dimensions, amounts, and other numerical data may be presented herein in a range format. A range format is used merely for convenience and brevity and should be interpreted flexibly to include the numerical values explicitly recited as the limits of the range, as well as to include all the individual numerical values or sub-ranges encompassed within that range as the individual numerical value and/or sub-range is explicitly recited. For example, a weight ratio range of about 1 wt% to about 20 wt% should be interpreted to include the explicitly recited limits of 1 wt% and 20 wt% and to include individual weights such as about 2 wt%, about 11 wt%, about 14 wt%, and sub-ranges such as about 10 wt% to about 20 wt%, about 5 wt% to about 15 wt%, etc.

# EXAMPLES

[0044] The following examples illustrate the technology of the present disclosure. However, it is to be understood that the following are merely illustrative of the housings, electronic devices, and methods herein. Numerous modifications and alternative methods and systems may be devised without departing from the present disclosure. Thus, while the technology has been described above with particularity, the following provides further detail in connection with what are presently deemed to be the acceptable examples. Additional film layers and/or method step elements illustrated in the examples are provided by way of example only, and can be practiced with or without these additional elements.

Example 1 – *Electronic Device with Multi-Layered Thermal Insulting Film*

[0045] A multi-layered thermal insulating film was prepared by adjusting a pH of a 60 wt% sodium silicate in water (a silane coupling fluid) to a pH of 5 with sodium hydroxide (NaOH). Agitating occurred while heating the admixture at a temperature of 30 °C for 30 minutes to form a pH-adjusted silane coupling fluid. 55 wt% of the pH-adjusted silane coupling fluid was mixed with 35 wt% of polyacrylic, a water-based polymer, for a period of time of about 45 minutes to form an aerogel precursor fluid. The aerogel precursor fluid was coated on a 25 µm thick layer of polyethylene terephthalate film. The aerogel precursor fluid on the polyethylene terephthalate film was baked to a temperature of about 120 °C for about 60 minutes to form a thermal insulating aerogel layer including a crosslinked silane coupling compound and the water-based polymer on the polyethylene terephthalate film. Polyurethane based pressure sensitive adhesive (a pressure- sensitive adhesive) was spray coated onto a surface of the polyethylene terephthalate film opposite of the thermal insulating aerogel layer. The film was adhesion baked at a temperature of about 130 °C for a period of time of about 15 minutes to form the multi-layered thermal insulating film. The multi-layered thermal insulating film was applied over a GPU choke (a heat generating electronic component) of a laptop by pressing the pressure-sensitive adhesive layer onto the GPU choke. A

housing was secured over the electronic components and the multi-layered thermal insulating film.

Example 2 – *Heat Testing*

[0046] An electronic device as described above in example 1, was tested for heat generation before and after application of the multi-layered thermal insulating film over the GPU choke to compare heat generated at exterior locations of the housing of the electronic device. The heat testing included placing the electronic device on a table top and operating the electronic device in a room having a temperature of 24.8 °C for 30 minutes and recording the maximum temperature during the operation thereof. The operation included 100% GPU and 100% CPU loading. The maximum temperature generated at the exterior of the housing was measured by placing a thermocouple sensor at each of three locations of the electronic device and reading the temperature at each location using a data recorder and DC power supply.

Table 1: Maximum Operating Temperature

| | **Electronic Device without Film (Temp. °C)** | **Electronic Device with Film (Temp. °C)** | **Delta** |
|---|---|---|---|
| Monitoring Point 1 | 42.7 | 42.8 | +0.1 |
| Monitoring Point 2 | 38.8 | 38.8 | 0 |
| Monitoring Point 3 | 37.2 | 35.4 | -1.8 |

The presence of the multi-thermal insulating film reduced the maximum operating temperature as indicated in Table 1. The reduction at Monitoring Point 3 was 1.8 °C. Monitoring point 3 was located over the GPU Choke. Accordingly, the multi-layered thermal insulating film resulted in reduced exterior temperatures during operation of the electronic device where the multi-layered thermal insulating film was applied to the heat generating electronic component.

# CLAIMS

What is Claimed Is:

1. A multi-layered thermal insulating film for an electronic device, comprising:

a pressure-sensitive adhesive layer including a pressure-sensitive adhesive; and

a thermal insulating aerogel layer including an aerogel comprising a cross-linked silane coupling compound and a water-based polymer, wherein the silane coupling compound is halo-, oxygen-, or C1-C3 alkoxy-substituted.

2. The multi-layered thermal insulation film of claim 1, wherein the pressure-sensitive adhesive includes a polymer selected form ethylene-vinyl acetate, polyimide, acrylic, silicone, polyurethane, styrene, styrene block copolymer, or a combination thereof.

3. The multi-layered thermal insulating film of claim 1, wherein the silane coupling compound is selected from $Si(OCH_3)_4$, $SiCl_4$, $K_2SiO_3$, $Na_2SiO_3$, or combination thereof prior to cross-linking, and wherein water-based polymer is selected from polyethyleneimine, polyvinyl alcohol, guar gum, gelatin, ethylene vinyl acetate, or a combination thereof prior to cross-linking.

4. The multi-layered thermal insulating film of claim 1, wherein the aerogel has a density from about 0.01 g/cm$^3$ to about 0.5 g/cm$^3$, a porosity from about 75% to about 99%, and a thermal conductivity from about 0.01 W/mk to about 0.03 W/mk.

5. The multi-layered thermal insulating film of claim 1, wherein the pressure-sensitive adhesive layer has a thickness from about 2 μm to about 60 μm and the thermal insulating aerogel layer has a thickness from about 50 μm to about 800 μm.

6. The multi-layered thermal insulating film of claim 1, further comprising a polyethylene terephthalate film layer immediately adjacent to the pressure-sensitive adhesive layer.

7. The multi-layered thermal insulating film of claim 6, wherein the polyethylene terephthalate film layer is included:

as a release liner positioned on an opposite surface of the pressure-sensitive adhesive layer relative to the thermal insulating aerogel layer;

as a layer positioned between the pressure-sensitive adhesive layer and the thermal insulating aerogel layer; or

both.

8. The multi-layered thermal insulating film of claim 1, further comprising a release liner immediately adjacent to the pressure-sensitive adhesive layer on an opposite side relative to the thermal insulating aerogel layer.

9. An electronic device, comprising:

a heat generating electronic component of an electronic device; and

a multi-layered thermal insulating film positioned on the heat generating electronic component, wherein the multi-layered thermal insulating film includes,

a pressure-sensitive adhesive layer including a pressure-sensitive adhesive; and

a thermal insulating aerogel layer including an aerogel comprising a cross-linked silane coupling compound and a water-based polymer, wherein the silane coupling compound is halo-, oxygen-, or C1-C3 alkoxy-substituted.

10. The electronic device of claim 9, further comprising a polyethylene terephthalate film layer between the pressure-sensitive adhesive layer and the thermal

insulating aerogel layer, the polyethylene terephthalate film layer having a thickness from about 5 μm to about 100 μm.

11. The electronic device of claim 9, wherein the multi-layered thermal insulating film is located on an exterior of a housing of the electronic device, and the pressure-sensitive adhesive adheres to the multi-layered thermal insulating film to the housing.

12. The electronic device of claim 9, wherein the multi-layered thermal insulating film is adhered directly to the heat generating electronic component, and the pressure-sensitive adhesive adheres to the multi-layered thermal insulating film to the heat generating electronic component.

13. A method of forming a multi-layered thermal insulating film for an electronic device, comprising:

combining from about 15 wt% to about 40 wt% of a silane coupling compound and from about 0.5 wt% to about 85 wt% water to form a silane coupling fluid, wherein the silane coupling compound is halo-, oxygen-, or C1-C3 alkoxy-substituted

adjusting a pH of the silane coupling fluid to form a pH-adjusted silane coupling fluid having a pH of about pH 5 to about pH 8;

admixing from about 10 wt% to about 30 wt% of a water-based polymer with from about 15 wt% to about 75 wt% of the pH-adjusted silane coupling fluid to form an aerogel precursor fluid;

baking the aerogel precursor fluid to a temperature ranging from about 80 °C to about 140 °C for a period of time from about 5 minutes to about 2 hours to form a thermal insulating aerogel layer including a crosslinked silane coupling compound and the water-based polymer; and

adhering a pressure sensitive adhesive directly or indirectly to the thermal insulating aerogel layer to form the multi-layered thermal insulating film that includes the thermal insulating aerogel layer and a pressure-sensitive adhesive layer.

14. The method of claim 13, wherein:

the silane coupling compound includes an alkali metal silicate and the adjusting includes lowering a pH of the silane coupling fluid with an acid selected from sulfuric acid, nitric acid, tartaric acid, phosphoric acid, formic acid, acetic acid, or citric acid; or

silane coupling compound includes silicon tetrachloride or tetramethyl orthosilicate and the adjusting includes raising a pH of the silane coupling fluid with a base selected from potassium hydroxide, sodium hydroxide, barium hydroxide, calcium hydroxide, or magnesium hydroxide.

15. The method of claim 12, further comprising applying a polyethylene terephthalate layer immediately adjacent to the pressure-sensitive adhesive:

as a release liner positioned on an opposite surface of the pressure-sensitive adhesive layer relative to where the thermal insulating aerogel layer is applied or is to be applied;

as an intervening layer positioned between the pressure-sensitive adhesive layer and the thermal insulating aerogel layer; or

both.

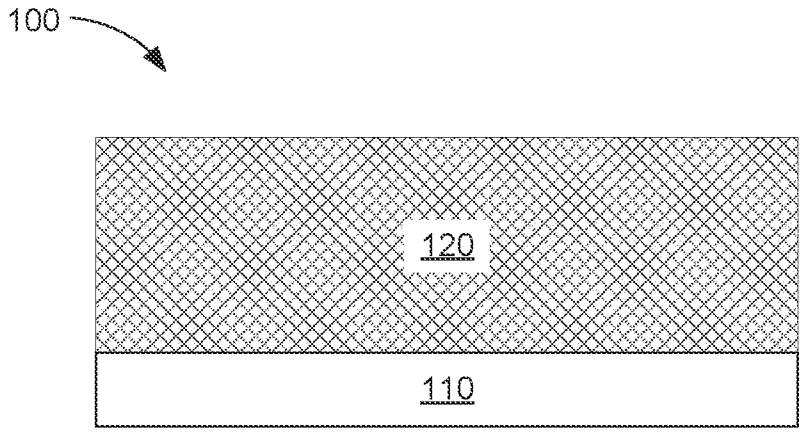


FIG. 1

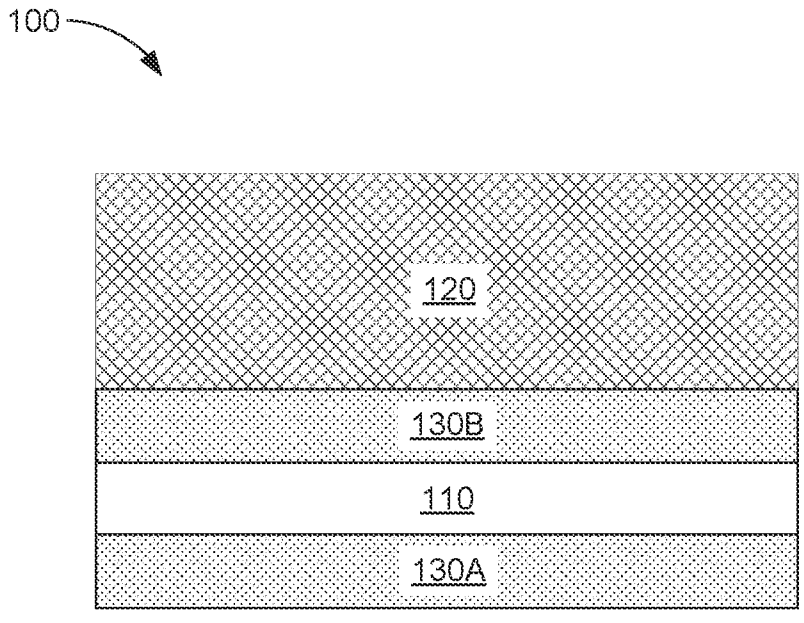


FIG. 2

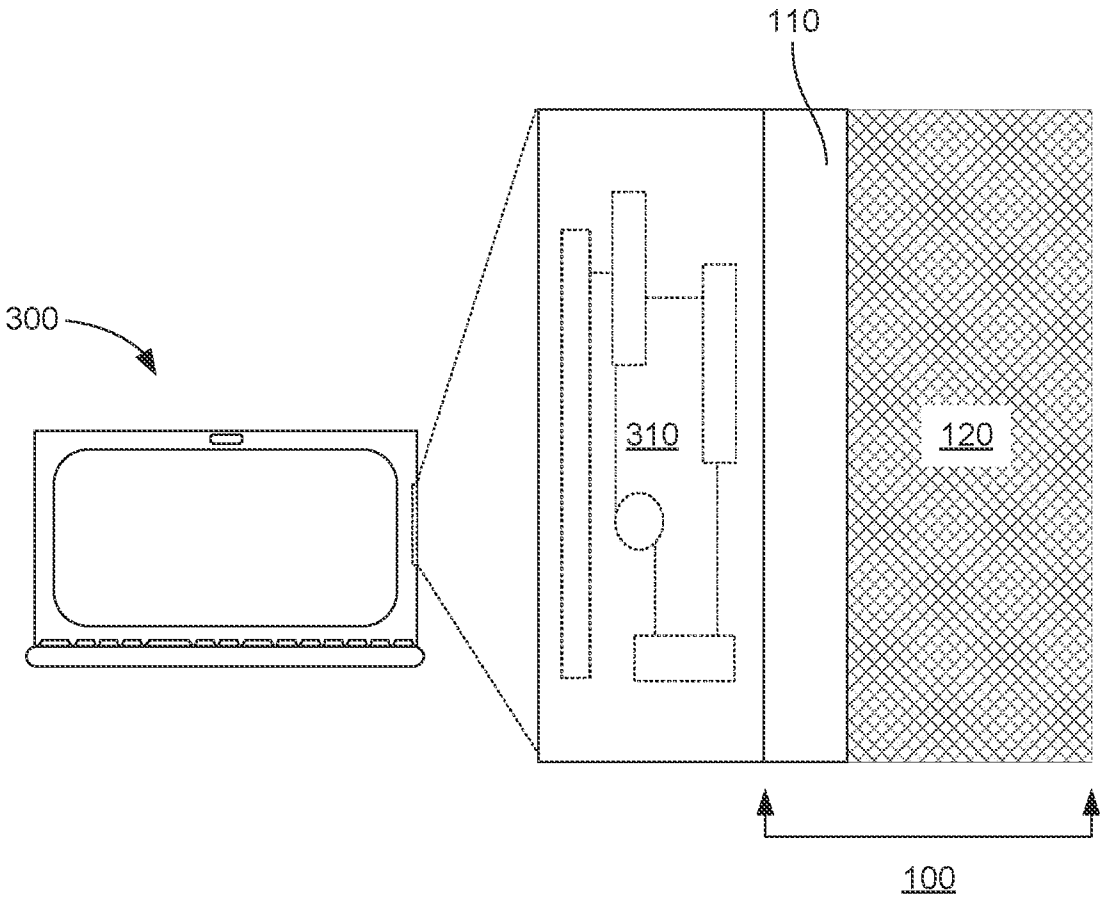


FIG. 3

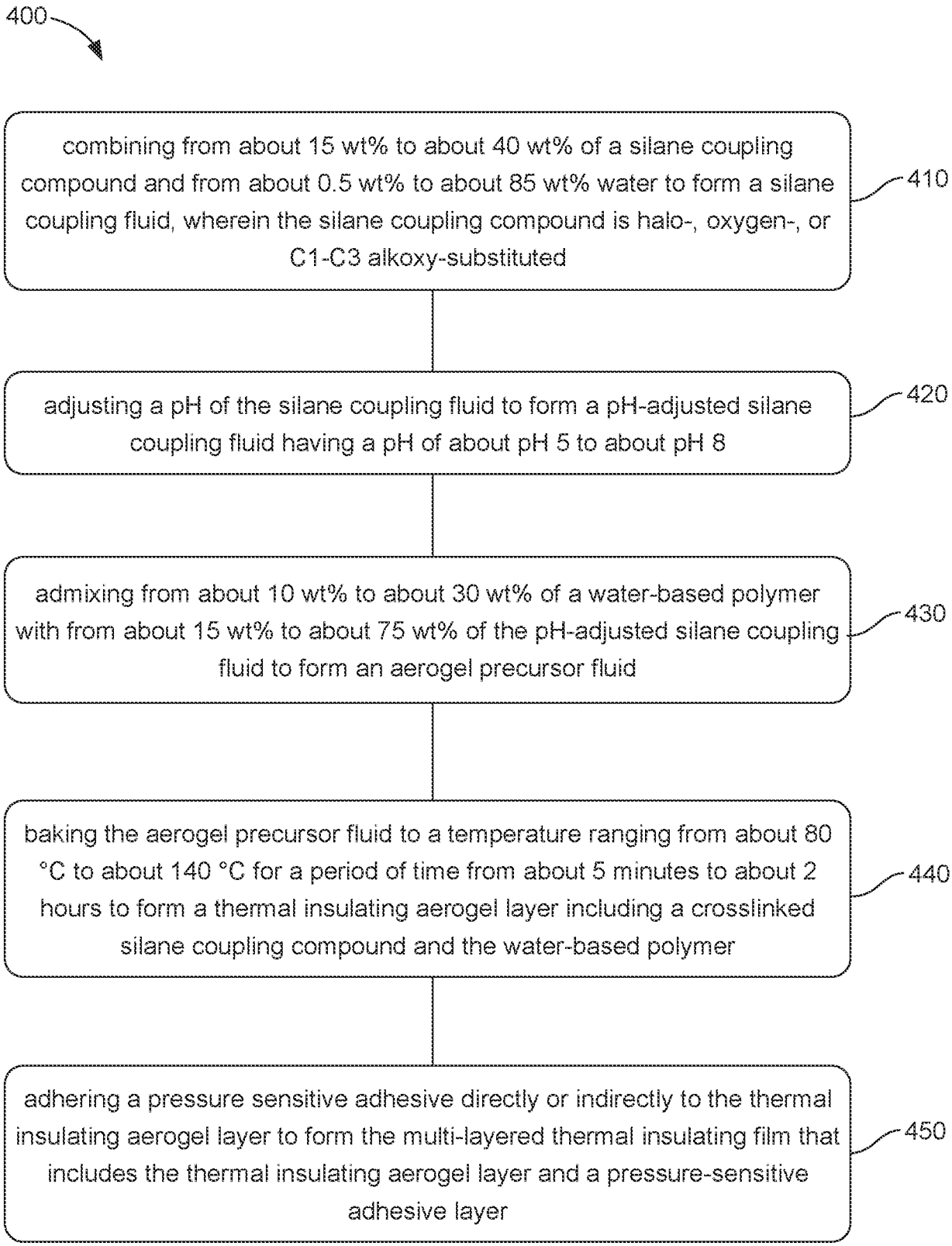
400
combining from about 15 wt% to about 40 wt% of a silane coupling compound and from about 0.5 wt% to about 85 wt% water to form a silane coupling fluid, wherein the silane coupling compound is halo-, oxygen-, or C1-C3 alkoxy-substituted
410
adjusting a pH of the silane coupling fluid to form a pH-adjusted silane coupling fluid having a pH of about pH 5 to about pH 8
420
admixing from about 10 wt% to about 30 wt% of a water-based polymer with from about 15 wt% to about 75 wt% of the pH-adjusted silane coupling fluid to form an aerogel precursor fluid
430
baking the aerogel precursor fluid to a temperature ranging from about 80 °C to about 140 °C for a period of time from about 5 minutes to about 2 hours to form a thermal insulating aerogel layer including a crosslinked silane coupling compound and the water-based polymer
440
adhering a pressure sensitive adhesive directly or indirectly to the thermal insulating aerogel layer to form the multi-layered thermal insulating film that includes the thermal insulating aerogel layer and a pressure-sensitive adhesive layer
450

FIG. 4

**INTERNATIONAL SEARCH REPORT**

International application No.

PCT/US 2021/021344

A. CLASSIFICATION OF SUBJECT MATTER

***C03C17/34*** *(2012.01)*

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)

G02B 6/122, B05D 1/20, H01L 21/20, C01B 33/159

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, K-PION, Esp@cenet, Information Retrieval System of FIPS

C. DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|---|---|---|
| X | CN 1335805 A (MATSUSHITA ELECTRIC WORKS LTD) 13.02.2002, p. 15 lines 24-26, p. 16 lines 12-21, p. 17 lines 25-32, p. 20 lines 19-29, p. 22 lines 5-12, 19-29, abstract, fig. 1b | 1, 9 |
| Y | | 2, 3, 5-8, 10-12 |
| A | | 4, 13-15 |
| Y | WO 2012/016842 A1 (HENKEL AG & CO KGAA et al) 09.02.2012, claim 8 | 2 |
| Y | CN 106019447 A (SUMITOMO CHEMICAL CO) 12.10.2016, [0076]-[0078] | 3 |
| Y | JP 5757825 B2 (SOKEN KAGAKU KK) 05.08.2015, [0106] | 5 |

[X] 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

"D" document cited by the applicant in the international application

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"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 |
|---|---|
| 09 November 2021 (09.11.2021) | 25 November 2021 (25.11.2021) |

| Name and mailing address of the ISA/RU: | Authorized officer |
|---|---|
| Federal Institute of Industrial Property,<br>Berezhkovskaya nab., 30-1, Moscow, G-59,<br>GSP-3, Russia, 125993<br>Facsimile No: (8-495) 531-63-18, (8-499) 243-33-37 | V. Selivanov<br><br>Telephone No. 499-240-60-15 |

**INTERNATIONAL SEARCH REPORT**

International application No.

PCT/US 2021/021344

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|---|---|---|
| Y | CN 111748296 A (HUIZHOU YIDU STATIONERY SUPPLIES CO LTD) 09.10.2020, claims 1, 6, 7, abstract | 6, 7 |
| Y | WO 2018/198924 A1 (HISAMITSU PHARMACEUTICAL CO., INC.) 01.11.2018, [0067] | 7, 8, 11 |
| Y | US 2014/0036953 A1 (HME CO., LTD et al.) 06.02.2014, [0026] | 10 |
| Y | US 2019/0092695 A1 (DENKA COMPANY LIMITED) 28.03.2019, [0029], [0039], [0044], [0062] | 12 |