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(54) **COOLING MATERIAL**

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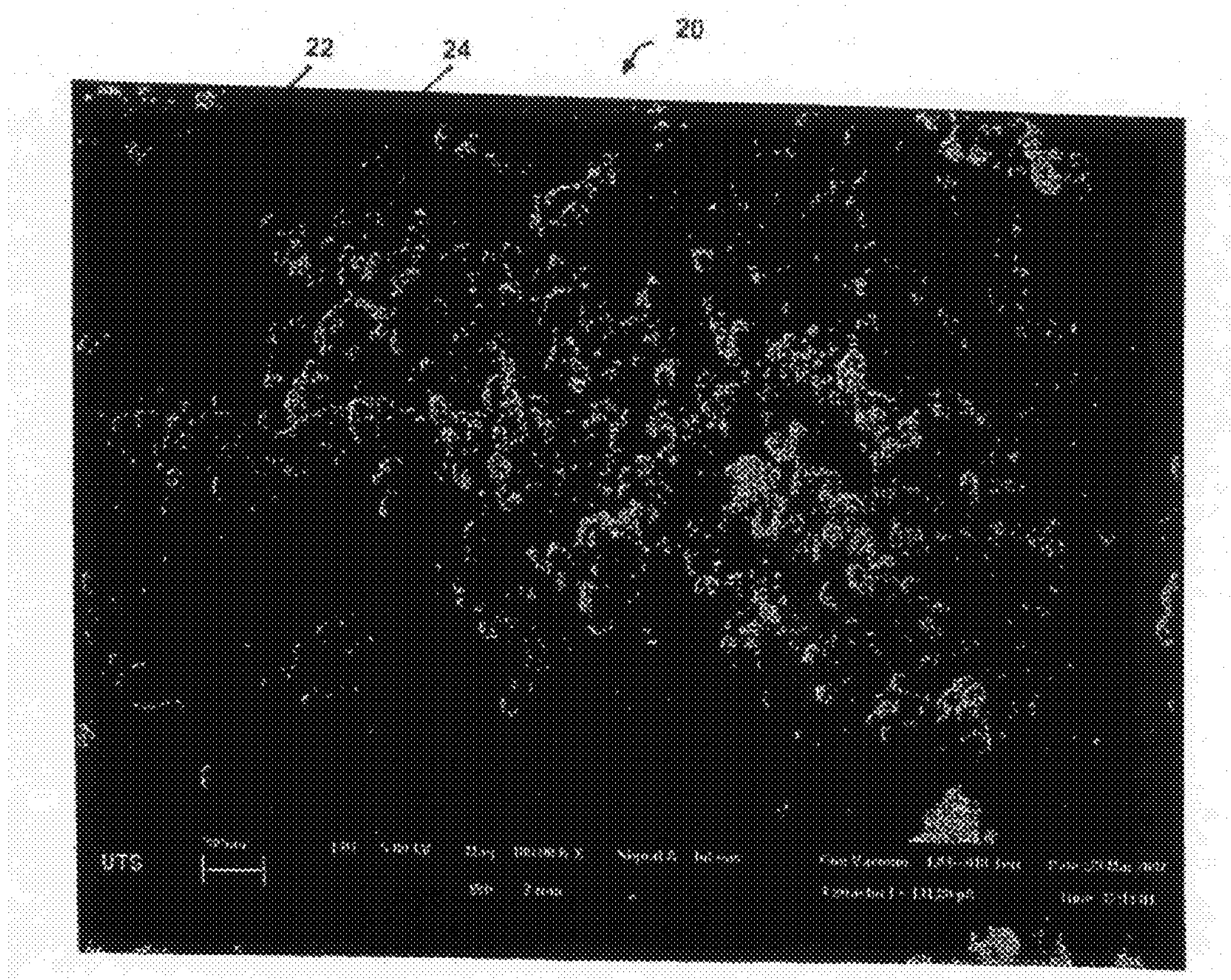
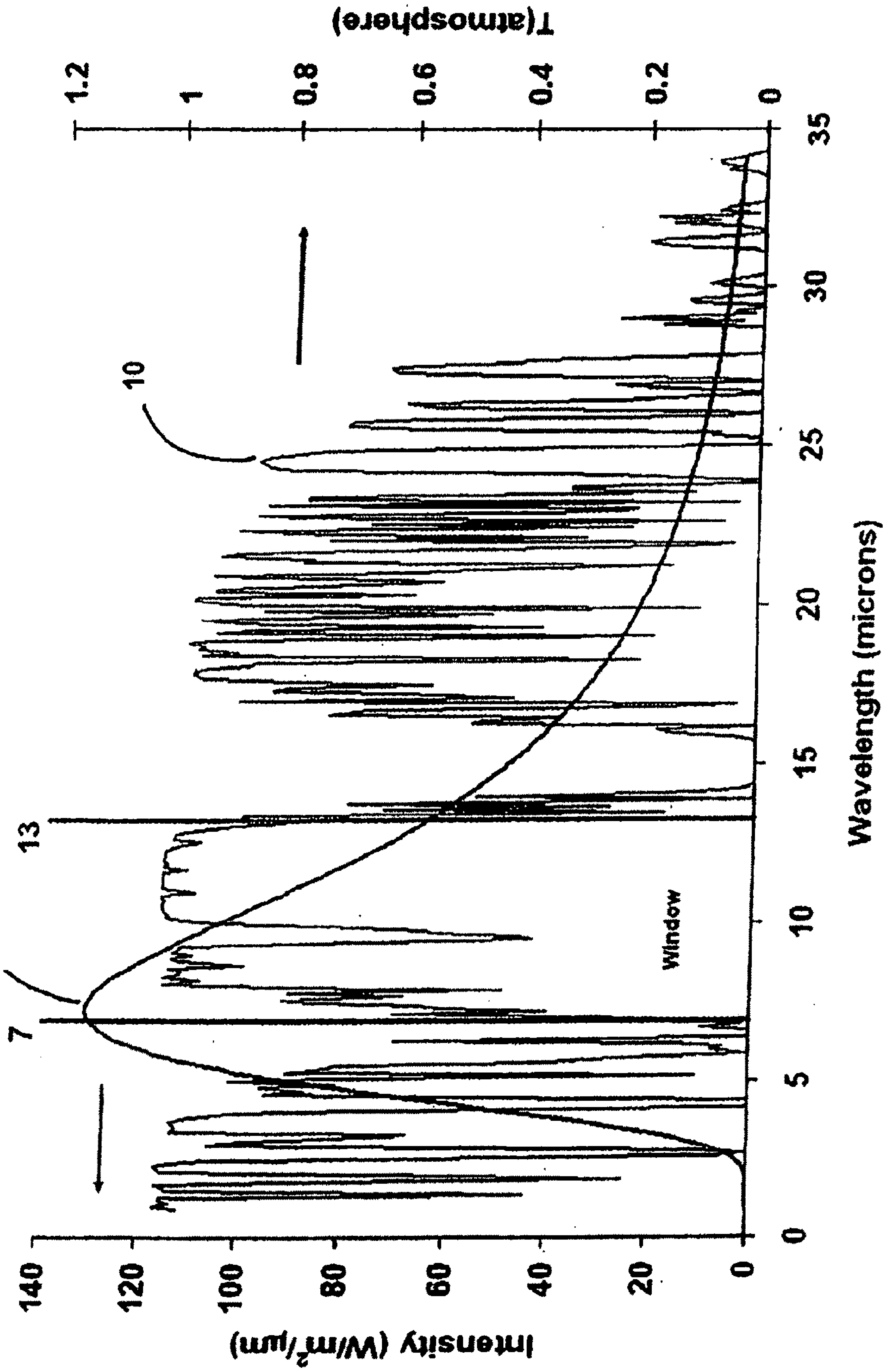
(57) **ABSTRACT**

The present disclosure provides a cooling material which comprises a first spectrally selective component that comprises particles. The particles are arranged for emission of radiation predominantly having a wavelength or wavelength range within an atmospheric window wavelength range in which the atmosphere of the earth has a reduced average absorption and emission compared with an average absorption and emission in an adjacent wavelength range. Consequently, the cooling material is arranged for emission of thermal radiation and absorption of radiation from the atmosphere within that wavelength range is reduced. The cooling material further comprises a second spectrally selective component having a property that distinguishes the second spectrally selective component from the first spectrally selective component and facilitates at least one desired function of the cooling material.




T(atmosphere)
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1
0.8
0.6
0.4
0.2
0
140
120
100
80
60
40
20
0
Intensity (W/m²/μm)
0
5
10
15
20
25
30
35
Wavelength (microns)
7
12
13
10
Window

Fig. 1

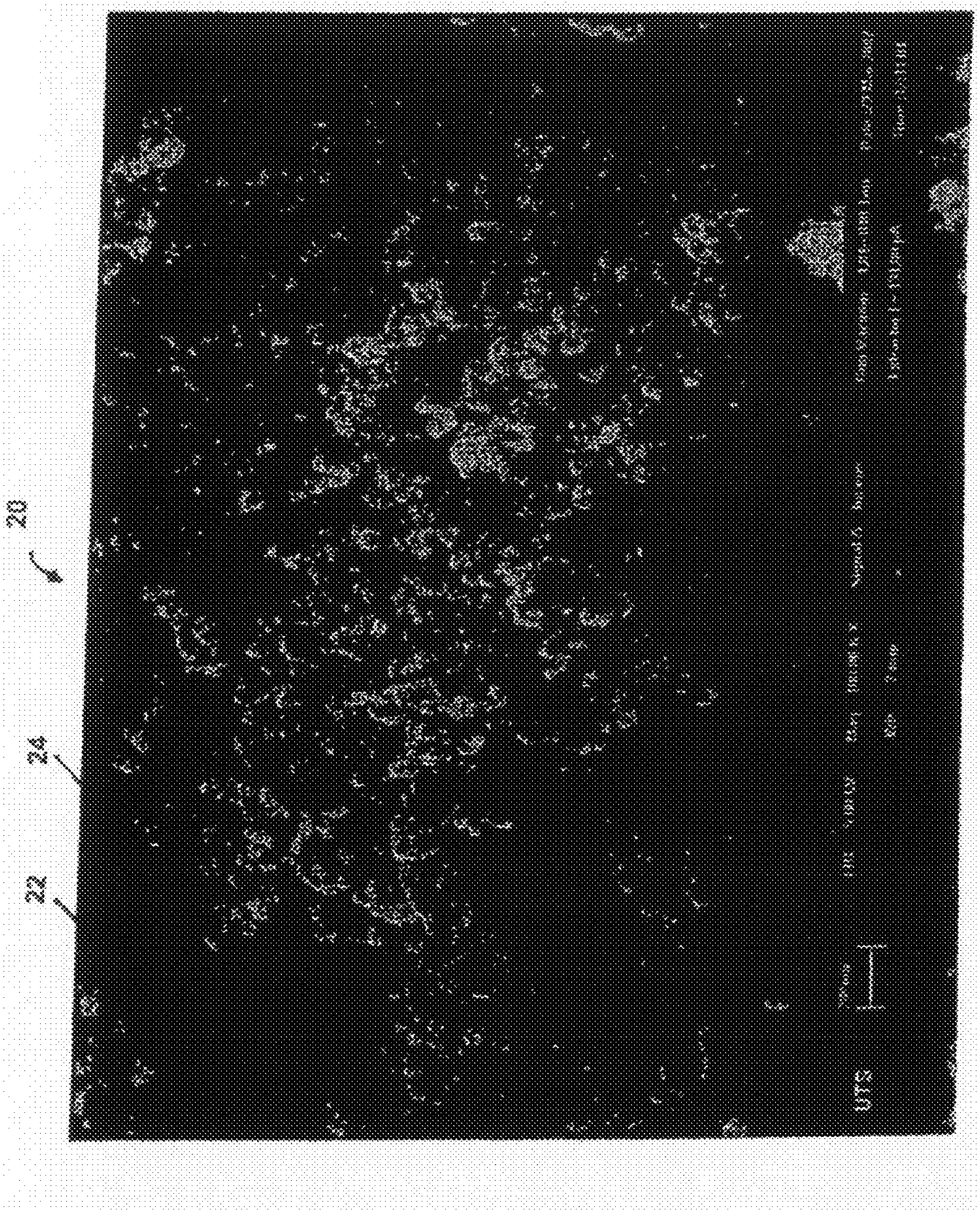

Fig. 2

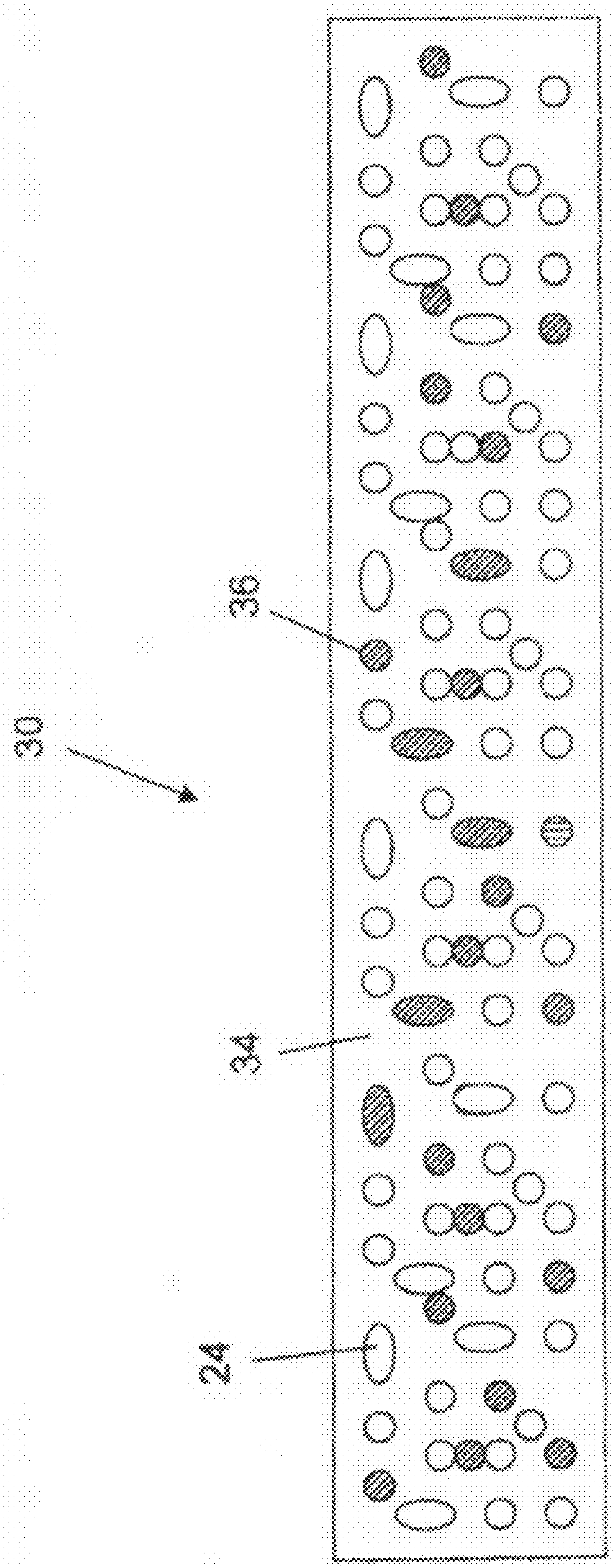

Fig. 3

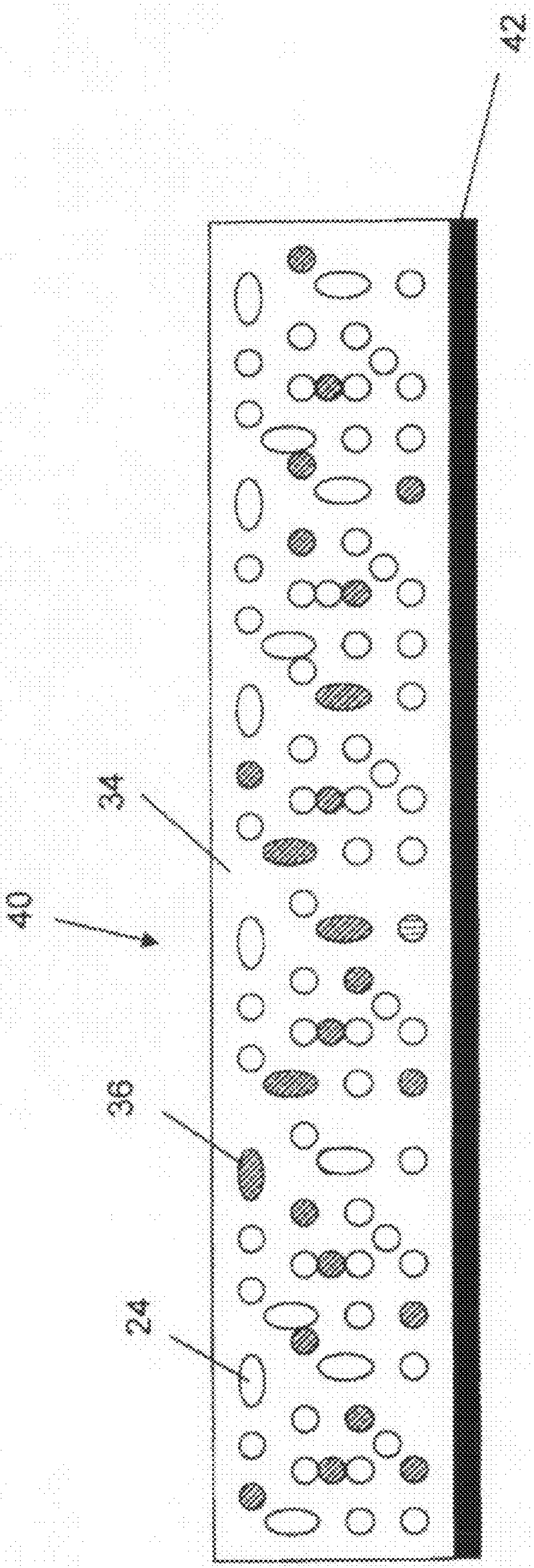

Fig. 4

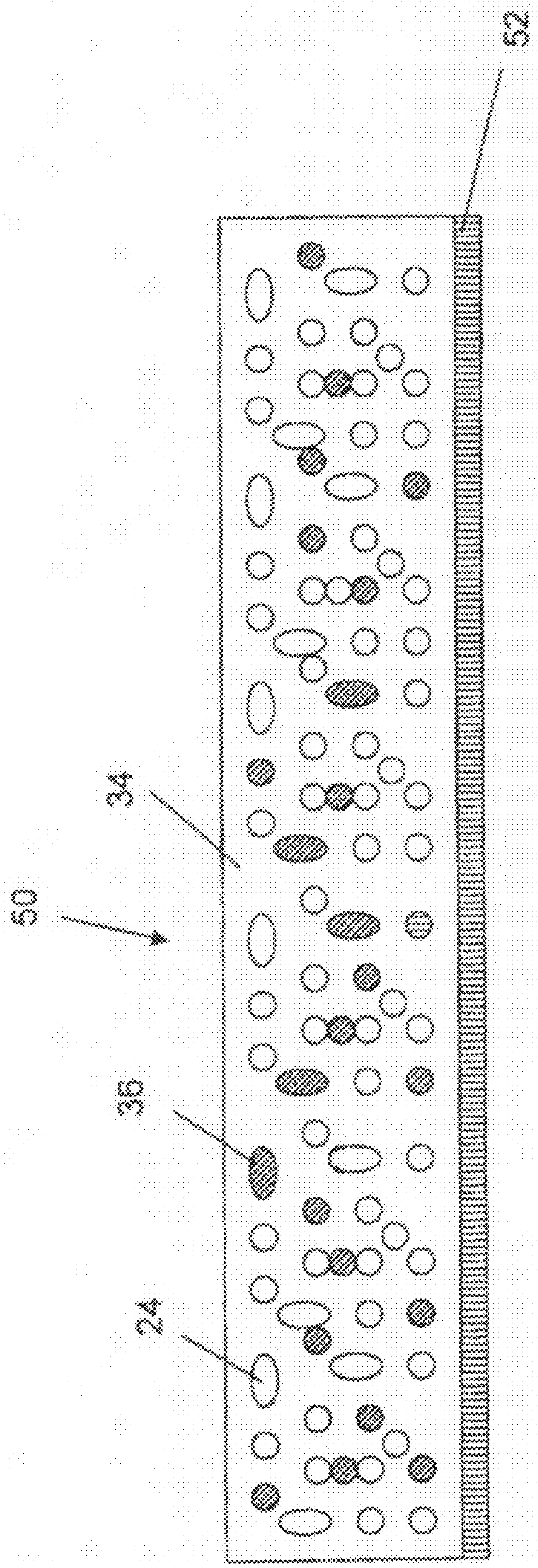

Fig. 5

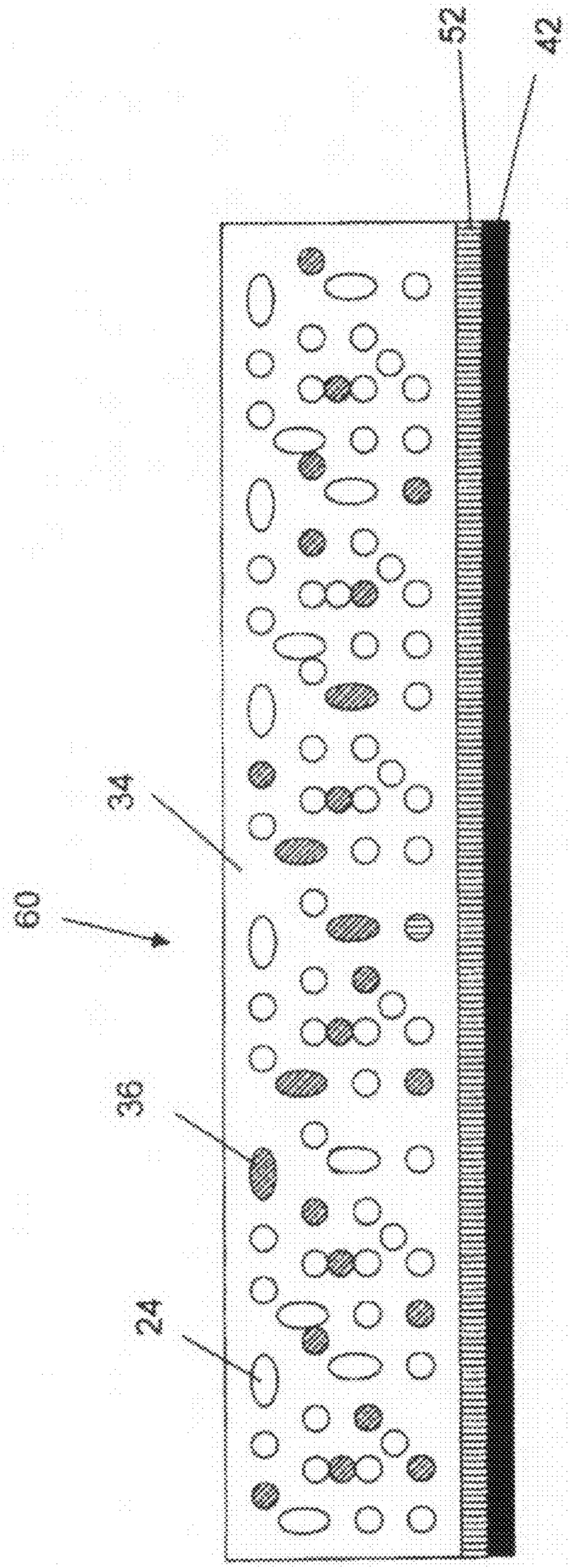

Fig. 6

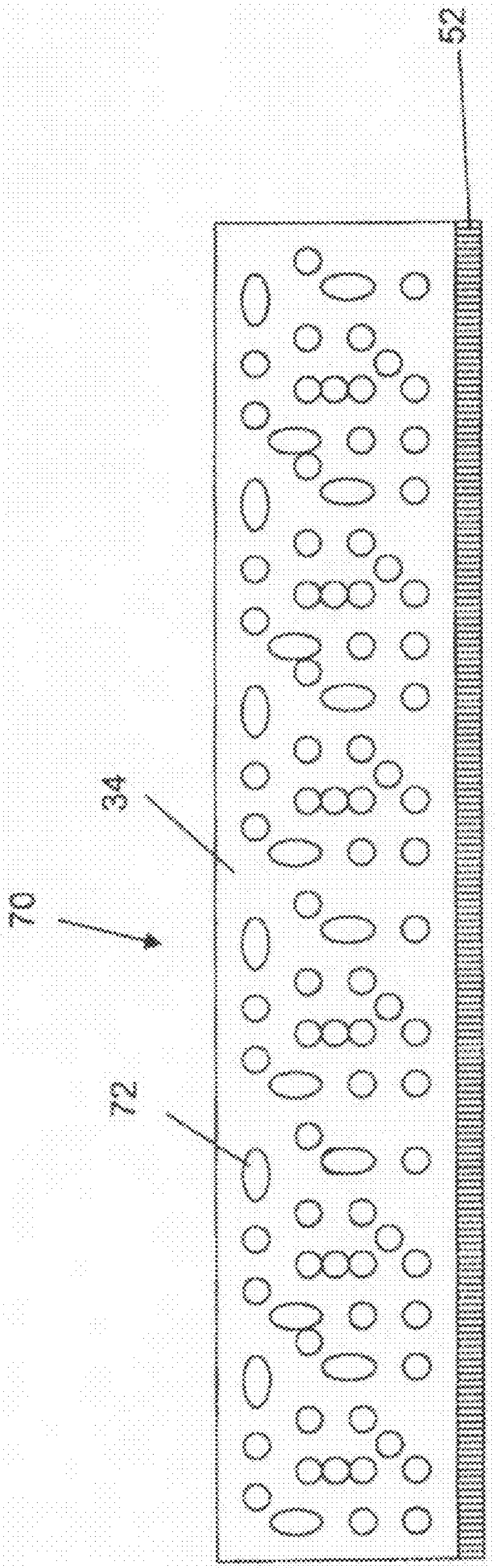

Fig. 7

COOLING MATERIAL

FIELD OF THE INVENTION

[0001] The present invention broadly relates to a cooling material.

BACKGROUND OF THE INVENTION

[0002] Various methods are used to cool interior spaces of buildings, refrigerate food, condense water or reduce the temperature of objects. These methods have in common that they require relatively large amounts of energy, which typically is provided in the form of electrical energy. For example, in countries which have a relatively warm climate the electrical energy required for cooling often exceeds the available electrical energy, which may result in a breakdown of a power grid. Further, electrical energy is at this time still at least partially generated using non-renewable energy resources, for example by burning coal, which is of concern for the environment and contributes to global warming. Consequently, it would be advantageous if cooling could be achieved in a manner that uses less energy. There is a need for technological advancement.

SUMMARY OF THE INVENTION

[0003] The present invention provides in a first aspect a cooling material which comprises:

[0004] a first spectrally selective component comprising particles arranged for emission of radiation predominantly having a wavelength or wavelength range within an atmospheric window wavelength range in which the atmosphere of the earth has a reduced average absorption and emission compared with an average absorption and emission in an adjacent wavelength range whereby the cooling material is arranged for emission of thermal radiation and absorption of radiation from the atmosphere within that wavelength range is reduced; and

[0005] a second spectrally selective component having a property that distinguishes the second spectrally selective component from the first spectrally selective component and facilitates at least one desired function of the cooling material.

[0006] Throughout this specification the term “spectrally selective component” is used for a component that has a wavelengths dependent property.

[0007] Because the atmosphere of the earth has very low absorption within the atmospheric window wavelength range, only a very small amount of radiation is returned from the atmosphere to the particles of the first spectrally selective component within that wavelength range and emitted radiation is largely directed through the atmosphere and into space where the typical temperature is of the order of 4 Kelvin.

[0008] The energy associated with the radiation emitted by the particles of the first component is at least partially, typically mainly, drawn from thermal energy of the cooling material or a medium that is in thermal contact with the cooling material and the thermal energy is emitted by or “pumped” away from the cooling material. As a consequence, cooling of the cooling material and the medium that may be in thermal contact with the cooling material is possible without the need for electrical energy and at low cost. Further, during the night, or when irradiation by the sun is avoided, cooling well below ambient temperature is possible.

[0009] The wavelength dependent property of the second spectrally selective component typically is arranged to facilitate the cooling. The second spectrally selective material may comprise a layer or particles and typically is arranged for emission and/or transmission and/or reflection and/or absorption of radiation in a spectrally selective manner. For example, the second spectrally selective component may be arranged for emission of radiation by a physical process that is identical to that is associated with the emission of radiation by the particles of the first spectrally selective component, but at a different or overlapping wavelength range. Alternatively, the second spectrally selective component may be arranged for emission of radiation by a physical process that differs to that associated with the emission of radiation by the particles of the first spectrally selective component. The second spectrally selective component may also be arranged for absorption of radiation.

[0010] The atmospheric window wavelength range typically includes a minimum of the average absorption of the atmosphere of the earth. The atmosphere has atmospheric windows within the wavelength ranges of 3 to 5 μm and 7.9 μm to 13 μm. Within these wavelength ranges the emission of the sun is also negligible and often regarded as zero, which has the added advantage that even during daytime the cooling material only absorbs very little radiation from the sun within that wavelength range.

[0011] In embodiments of the present invention the cooling material is arranged to enable cooling to temperatures that are 5°, 10°, 20° below an ambient temperature or even lower.

[0012] The cooling material may also be arranged to extract heat at a finite rate at a temperature below ambient. The cooling material may be arranged so that cooling rates such as 40, 60, 80 W per m^2 of cooling material area are possible at temperatures that are 5°, 10° or more below ambient temperature.

[0013] The particles of the first spectrally selective component may be arranged for generation of ionic surface plasmon resonances having a wavelength or wavelength range within the atmospheric window wavelength range.

[0014] Throughout this specification the term “ionic surface plasmon” is used for a surface plasmon excitation that involves movement of ions, such as that often referred to as “Fröhlich resonance”.

[0015] The wavelength of the ionic surface plasmons depends on the composition, shape, relative orientation and size of the particles, which typically are nano-sized particles. By controlling the composition and/or shape and/or size and/or relative orientation of the particles, it is consequently possible to control the wavelength range of the ionic surface plasmons.

[0016] The particles of the first spectrally selective component typically are arranged so that at least some, typically the majority or all, of the ionic surface plasmons have a wavelength within the wavelength range from 1-7 μm, 2-6 μm, 3-5 μm, and/or any one of 5-16 μm, 7-14 μm, 8-13 μm and 7.9-13 μm.

[0017] However, it is to be appreciated that alternatively the particles of the first spectrally selective component may be arranged so that the ionic surface plasmons are generated at a wavelength range that is partially outside the atmospheric window wavelength range. Further, the atmospheric window wavelength range may be one of a plurality of atmospheric window ranges, such as the wavelength range of 3-5 μm and 7.9 to 13 μm.

[0018] In one specific embodiment of the present invention the particles of the first spectrally selective component comprise, or may be entirely composed of, SiC or another suitable material.

[0019] Alternatively, the particles of the first spectrally selective component may be arranged for emission of radiation by a physical mechanisms other than that associated with the generation of ionic surface plasmons. In this case the particles of the first spectrally selective component may for example comprise SiO, silicon oxynitride or any other suitable material that is arranged for emission of radiation having a wavelength within the atmospheric window wavelength range.

[0020] The second spectrally selective component may also comprise particles. The particles of the first spectrally selective component and the particles of the second spectrally selective component may be dispersed within another component, such as a polymeric material, or may be distributed on a substrate. The particles of the second spectrally selective component may also be arranged for emission of radiation having a wavelength within the atmospheric window wavelength range, for example by generation of ionic surface plasmons.

[0021] Alternatively, the particles of the second spectrally selective component may not be arranged for generation of ionic surface plasmons, but may be arranged for emission of radiation by other physical mechanisms. In this case the particles of the second spectrally selective component may for example comprise SiO, silicon oxynitride or any other suitable material that is arranged for emission of radiation having a wavelength within or outside the atmospheric window wavelength range within. Further, the particles of the second spectrally selective component may be arranged for absorbing radiation by generating electronic surface plasmons.

[0022] Throughout this specification the term "electronic surface plasmon" is used for a surface plasmon excitation that involves collective motion of electrons.

[0023] If the particles of the second spectrally selective component are arranged for generation of electronic surface plasmons, the particles typically have a size, shape and/or composition and/or orientation that is selected so that the radiation is absorbed at a desired wavelength or wavelength range.

[0024] The cooling material may comprise a polymeric material that may be transmissive for radiation of a predetermined range of wavelength. At least a portion of the cooling material may be of a clear or opaque appearance. For example, the polymeric material may be arranged for light diffusion by incorporation of light scattering particles of a suitable size.

[0025] In first specific embodiment of the present invention the cooling material comprises at least one layer or foil that comprises a component material that is substantially transparent in the visible and/or in the near infrared and/or in the infrared spectral range. For example, the at least one layer or foil may comprise the polymeric material in which the particles of the first and/or second component are embedded or adjacent to which the particles of the first and/or second component are positioned. The cooling material may be freestanding and may form a part of a window, roof glazing, skylight or the like.

[0026] If the second spectrally selective component is provided in the form of a layer, the particles of the first spectrally selective component may also be embedded in or positioned adjacent that layer. Further, the layer of the second spectrally selective material may be positioned adjacent the substantially transparent layer.

[0027] In a second specific embodiment of the present invention the cooling material is arranged to reflect at least some incident radiation, such as radiation from the atmosphere and/or from the sun in the daytime. The cooling material may comprise a reflective material that is provided in the form of a layer positioned below the particles and may be arranged to reflect at least a portion of incident radiation. For example, the cooling material may be a coating that forms a part of a roof tile or sheet or may form a part of any other suitable object. Alternatively or additionally, the cooling material may comprise reflective particles that are dispersed within an at least partially transparent material, such as the above-described polymeric material. For example, the particles of the first and/or second component may be embedded or positioned adjacent to the polymeric material.

[0028] The cooling material may be arranged so that the majority of incident radiation is reflected. In this case the cooling material has the significant advantage of improved cooling efficiency as then the cooling material typically only has increased absorption within the atmospheric window energy range where the intensity of incident radiation is much reduced or negligible.

[0029] The reflective material may also reflect incident radiation having a wavelength within the atmospheric window wavelength range.

[0030] In a further specific embodiment of the present invention the particles of the first spectrally selective component are arranged for generation of ionic surface plasmons and the second spectrally selective component comprises particles that are also arranged for generation of ionic surface plasmons at a wavelength or wavelength range that differs from that of the particles of the first spectrally selective component. For example, this may be achieved by selecting a shape, size, orientation or composition that is different to that of the particles of the first spectrally selective component. The particles of the second spectrally selective component typically are arranged to emit radiation at a wavelength or wavelength range at which the particles of the first spectrally selective component have reduced emission so that utilisation of the available atmospheric window wavelength range is improved.

[0031] In another specific embodiment of the present invention the particles of the first spectrally selective component are arranged for generation of ionic surface plasmons and the second spectrally selective component comprises particles that are arranged for generation of electronic surface plasmons. In this case the particles of the second spectrally selective component may be arranged for absorption of radiation in the near infrared (NIR) wavelength. The cooling material typically is arranged to block at least a portion of incident solar radiation, which further improves the cooling that can be achieved with the cooling material when exposed to sunlight. For example, the particles of the second spectrally selective component may in this case comprise LaB_6, SbSn oxide, aluminium doped ZnO or another suitable material. In this embodiment the cooling material typically is arranged so that a portion of the thermal energy, that is present as a consequence of the absorbed solar radiation in the infrared (NIR) wavelength range, is emitted by the particles of the first spectrally selective component.

[0032] The particles of the second spectrally selective component may be arranged for generation of electronic surface plasmons having wavelengths at or near the visible wavelength range. In this case the cooling material typically is arranged to block at least a portion of the visible light originating from the sun, whereby the cooling material may exhibit a particular colour. For example, in this case the particles of the second spectrally selective component may comprise Au, TiN or other suitable materials.

[0033] In addition, the cooling material may comprise a layered structure that is arranged to reflect thermal radiation from the atmosphere or a portion of visible light. For example, the layered structure may comprise thin layers of metal and dielectric materials.

[0034] The particles of the second spectrally selective component may have a diameter within the range of 10-100 nm, typically of the order of 50 nm or less. The second spectrally selective material may also comprise particles having differing compositions and/or shapes and/or sizes and/or relative orientations.

[0035] It is to be appreciated that in embodiments of the present invention the first and the second spectrally selective component may each comprise a combination of particles arranged for generation of ionic plasmons, particles arranged for generation of electronic surface plasmons and particles that are not arranged for generation of surface plasmons (such as SiO particles).

[0036] It is to be appreciated that in variations of the above-described embodiments the cooling material may not necessarily comprise particles that are arranged for emission of thermal radiation having a wavelength within the atmospheric window wavelength range, but the particles may be replaced by at least one layer that is arranged for emission of thermal radiation having a wavelength within the atmospheric window wavelength range. For example, the at least one layer may comprise a granular structure, a porous structure or may have a surface that is profiled so that the at least one layer is arranged for generation of ionic surface plasmon resonances having a wavelength or wavelength range within the atmospheric window wavelength range. Alternatively, the at least one layer may be a part of a multi-layered structure that is arranged for generation of ionic surface plasmon resonances having a wavelength or wavelength range within the atmospheric window wavelength range.

[0037] The present invention provides in a second aspect a cooling material which comprises:

[0038] a spectrally selective component comprising at least one layer arranged for receiving thermal energy and emitting at least a portion of the received thermal energy in the form of the thermal radiation, the thermal radiation predominantly having a wavelength or wavelength range within an atmospheric window wavelength range in which the atmosphere of the Earth has a reduced average absorption and emission compared with an average absorption and emission in an adjacent wavelength range whereby absorption of radiation from the atmosphere is reduced.

[0039] The spectrally selective component typically is a first spectrally selective component and the cooling material typically comprises a second spectrally selective component having a property that distinguishes the second spectrally selective component from the first spectrally selective component and facilitates at least one desired function of the cooling material. The second spectrally selective component typically is arranged to facilitate cooling of the cooling material.

[0040] The atmospheric window wavelength range typically is a wavelength range from 3 to 5 μm and/or from 7.9 μm to 13 μm.

[0041] The at least one layer typically is arranged for generation of ionic surface plasmon resonances having a wavelength or wavelength range within the atmospheric window wavelength range.

[0042] The at least one layer may have a structural property that is selected so that the at least one layer is arranged for generation of ionic surface plasmon resonances having a wavelength or wavelength range within the atmospheric window wavelength range. For example, the at least one layer may comprise grains, or may at least in part be of a porous structure and the structural property may be associated with a grain size or a thickness of residual solid between pores, respectively. Further, the at least one layer may have a surface roughness and the structural property may be associated with thickness or width of surface features of the at least one layer. The grain size, the thickness of residual solid between pores and the thickness or width of surface features of the at least one layer typically are within the range of 50 nm-150 nm.

[0043] The at least one layer may also be a part of a multi-layered structure having layer thicknesses that are selected so that the multi-layered structure is arranged for generation of ionic surface plasmon resonances having a wavelength or wavelength range within the atmospheric window wavelength range.

[0044] The present invention provides in a third aspect a method of cooling using a cooling material for emission of thermal energy, the cooling material comprising a first spectrally selective component and a second spectrally selective component, the second spectrally selective component having a property that distinguishes the second spectrally selective component from the first spectrally selective component, the method comprising:

[0045] emitting a portion of the thermal energy from the first spectrally selective component in the form of radiation having a wavelength within the atmospheric window wavelength range in which the atmosphere of the earth has low or negligible average absorption and emission compared with the average absorption and emission in an adjacent wavelength range; and

[0046] emitting a portion of the thermal energy from the second spectrally selective component.

[0047] The first spectrally selective component may comprise particles or at least one layer arranged for emitting a portion of the thermal energy in the form of radiation having a wavelength within the atmospheric window wavelength range. For example, the at least one layer may have a structural property that is selected so that the first spectrally selective component is arranged for emitting a portion of the thermal energy in the form of radiation having a wavelength within the atmospheric window wavelength range. Alternatively, the at least one layer may be a part of a multi-layered structure having layer thicknesses that are selected so that the first spectrally selective component is arranged for emitting a portion of the thermal energy in the form of radiation having a wavelength within the atmospheric window wavelength range.

[0048] The step of emitting a portion of the thermal energy from the second spectrally selective component typically comprises emitting radiation by a physical process that is identical to that associated with the emission of radiation by the particles of the first spectrally selective component, but at a wavelength or wavelength range that differs from that of the first spectrally selective component. Alternatively, the step of emitting a portion of the thermal energy from the second spectrally selective component may comprise emitting radiation by a physical process that differs to that associated with the emission of radiation by the particles of the first spectrally selective component.

[0049] In one specific example the step of emitting a portion of the thermal energy from the first spectrally selective component comprises generating ionic surface plasmon resonances having a wavelength or wavelength range within the atmospheric window wavelength range. At least some of the ionic surface plasmons typically have a wavelength within the wavelength range from 1-7 μm, 2-6 μm, 3-5 μm, and/or any one of 5-16 μm, 7-14 μm, 8-13 μm and 7.9-13 μm.

[0050] The step of emitting a portion of the thermal energy from the first spectrally selective component may also comprise generating the ionic surface plasmons at a wavelength range that is partially outside the atmospheric window wavelength range.

[0051] The step of emitting a portion of the thermal energy from the second spectrally selective component may comprise emitting radiation having a wavelength within the atmospheric window wavelength range. For example, the step of emitting a portion of the thermal energy from the second spectrally selective component may comprise emitting radiation by generation of ionic surface plasmons. Alternatively, the step of emitting a portion of the thermal energy from the second spectrally selective component may comprise absorbing radiation by generating electronic surface plasmons.

[0052] The method typically comprises reflecting at least some incident radiation. For example, the method may comprise reflecting incident radiation having a wavelength within the atmospheric window wavelength range.

[0053] The method may comprise controlling at least one of the composition of the first spectrally selective component and a structural property of the first spectrally selective component to control the wavelength range of ionic surface plasmons.

[0054] The invention will be more fully understood from the following description of specific embodiments of the invention. The description is provided with reference to the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0055] FIG. **1** shows a transmission spectrum of the atmosphere of the earth as a function of wavelength,

[0056] FIG. **2** shows a cooling material according to a first embodiment of the present invention,

[0057] FIG. **3** shows a cooling material according to a second embodiment of the present invention,

[0058] FIG. **4** shows a cooling material according to a third embodiment of the present invention,

[0059] FIG. **5** shows a cooling material according to a fourth embodiment of the present invention,

[0060] FIG. **6** shows a cooling material according to a fifth embodiment of the present invention, and

[0061] FIG. **7** shows a cooling material according to a sixth embodiment of the present invention.

DETAILED DESCRIPTION OF SPECIFIC EMBODIMENTS

[0062] Referring initially to FIGS. **1** and **2**, a cooling material and a method of cooling a material according to a specific embodiment of the present invention are now described.

[0063] FIG. **1** shows a transmission spectrum **10** of the atmosphere of the earth for substantially cloud free conditions. The average transmission is increased to nearly 1 within the range of approximately 7.9 to 13 μm compared to adjacent wavelength ranges. Further, the average transmission of the atmosphere is increased within a wavelength range of 3-5 μm. Within these wavelength ranges the atmosphere of the earth has "windows". Plot **12** is an estimation of the emission spectrum of a black body having a temperature of 100° C., which was calculated using Wein's law and gives an example of the emission spectrum for a medium that may be cooled using the cooling material according to embodiments of the present invention.

[0064] FIG. **2** shows a secondary electron microscopy micrograph of a cooling material according to a specific embodiment of the present invention. The cooling material **20** comprises a reflective metallic layer **22**, which in this embodiment is provided in the form of an aluminum layer positioned on a substrate. Further, the cooling material **20** comprises SiC particles **24**, which are positioned on the metallic layer **22**. The SiC particles **24** have an average diameter of approximately 50 nm and are deposited using suitable spin coating procedures.

[0065] The SiC particles **24** are in this embodiment nanoparticles and the majority of the surface of the particles **24** is exposed to air. The particles **24** show resonantly enhanced absorption and emission of radiation at a wavelength range of 10 to 13 μm. Within that wavelength range ionic surface plasmons are generated. The wavelength range of resonant ionic surface plasmon emission is within the above-described atmospheric window wavelength range. For that wavelength range the average absorption of the atmosphere of the earth is very low and consequently very little radiation in this wavelength range is transferred from the atmosphere to the cooling material **20**.

[0066] The energy associated with the emitted radiation is largely drawn from the thermal energy of the particles **24** and/or from a medium that is in thermal contact with the particles **24**. Due to the atmospheric window, the emitted radiation is largely transmitted through the atmosphere and directed to space where the temperature typically is 4 Kelvin. Consequently, the cooling material **20** functions as a pump of thermal energy even if the cooling material, or a medium that is in thermal contact with the cooling material, has a temperature below ambient temperature.

[0067] The reflective material **22** has the added advantage that a large portion of incident radiation is reflected away from the cooling material **20** and consequently thermal absorption of radiation having a wavelength within or outside the atmospheric window is reduced, which increases cooling efficiency.

[0068] The energy of the ionic surface plasmons depends on the composition of particles, the size of the particles, the shape of the particles and their orientation relative to each other. By selecting properties of the particles **24**, it is possible to control the energy of the ionic surface plasmons. For example, the particles **24** may be spherical, may have an elliptical shape or any other suitable shape.

[0069] The particles **24** may comprise a first component of particles having a first shape, size, composition or orientation and a second component of particles having a second shape, size, composition or orientation. In this case the first and second components are selected so that the particles of the first and second components result in generation of ionic surface plasmons at differing wavelength ranges within the atmospheric windows.

[0070] In variations of the above-described embodiment the particles **24** may be composed of other suitable materials that show ionic surface plasmon resonances, such as BN and BeO. Further, the particles **24** may also be composed of materials that are not arranged for ionic plasmon generation at a wavelength within the atmospheric window wavelength range, but may be arranged for emission of radiation within that wavelength range by any other possible mechanism. For example, SiO, silicon oxynitride particles exhibit relatively strong emissions within that wavelength range.

[0071] The reflective material **22** improves the cooling efficiency. However, it is to be appreciated that the cooling material may not necessarily comprise a reflective material. Further, the particles **24** may be embedded in a transparent material, such as a suitable polymeric material that is positioned upon the reflective material **22**. For example, the polymeric material may comprise polyethylene or a fluorinated material.

[0072] Referring now to FIG. **3**, a cooling material according to a second specific embodiment of the present invention is now described. In this embodiment the cooling material **30** also comprises the above-described particles **24**. In this example, however, the particles **24** are positioned within a matrix of a polymeric material **34** that is largely transparent to thermal radiation within a black body wavelength range, such as radiation having a wavelength within the range of 3-28 or a wavelength range outside one or both of 3-5 and 7.9-13 μm, or most of solar spectral range in addition to the black body radiation range. For example, the polymeric material **34** may comprise polyethylene or a fluorinated polymeric material.

[0073] In contrast to the cooling material **20**, incident radiation is not reflected, but largely transmitted through the cooling material **30**, which also reduces thermal absorption of radiation directed to the cooling material **30** and thereby improves the cooling efficiency.

[0074] In addition, the cooling material **30** comprises particles **36**. In general, the particles **36** have a spectrally selective property that complements a spectrally selective property of the particles **24**. In this example, the particles **36** are arranged for generation of electronic surface plasmons in the near infrared (NIR) wavelength range. Within that wavelength range the particles **36** absorb radiation, such as radiation originating from the sun. This inhibits transmission of a portion of incident radiation, which facilitates cooling. In this embodiment the cooling material **30** is arranged so that the thermal energy, that is present as a consequence of the absorbed solar radiation, is emitted by the particles **24**.

[0075] For example, the cooling material **30** may be provided in the form of a skylight or a window. In this case the cooling material **30** typically is arranged so that a large portion of the visible light originating from the sun can penetrate through the cooling material **30**. The particles **24** emit radiation within the atmospheric window wavelength range, which results in cooling, and the particles **36** partially "block" thermal radiation originating from the sun which facilitates the cooling.

[0076] For example, the particles **36** may comprise indium tin oxide, tin oxide, LaB6, SbSn oxide, or aluminium doped ZnO. It is to be appreciated, however, that in variations of the above-described embodiment the particles **36** may also be arranged for generation of electronic surface plasmons at any other suitable wavelength range.

[0077] In addition, the cooling material **30** may comprise a layered structure of dielectric and/or metallic materials having layer thicknesses that are selected to effect reflection of thermal radiation, such as thermal radiation originating from the atmosphere, which further facilitates cooling.

[0078] Further, the cooling material **30** may also comprise a layer structured material that is arranged so that a portion of light within the visible wavelength range is reflected and light that is transmitted though the cooling material **30** is of a particular colour, which has advantageous applications for aesthetic purposes.

[0079] Alternatively, the particles **36** may not be arranged for generating of surface plasmons, but may be arranged for strong absorption at a predetermined wavelength range in a manner such that the spectrally selective property of the particles **24** is complemented.

[0080] The cooling material **30** may be a free-standing material. Alternatively, the cooling material **30** may be a coating, such as a paint coating that is applied to an object.

[0081] The polymeric material **34** may be a clear polymeric material but may also be a translucent or opaque material that is arranged for scattering of light. If the polymeric material **34** is clear, the incorporated particles typically have a size that is smaller than 50 nm, which avoids light scattering. If light scattering is desired and the polymeric material **34** should be of an opaque appearance, particles having a diameter larger than 50 nm typically are incorporated to effect the light scattering.

[0082] Referring now to FIG. **4**, a cooling material **40** according to a third specific embodiment of the present invention is now described. The cooling material **40** corresponds to the cooling material **30** shown in FIG. **3** and described above, but is in this embodiment positioned on a reflective layer **42**. The cooling material **40** is particularly suited for cooling an object or medium that may be in thermal contact with the cooling material **40**. In this embodiment the reflective layer **42** is a metallic layer that is arranged to reflect radiation having a wide wavelength range and originating, for example, from the sun.

[0083] For example, the reflective layer **42** may be arranged to reflect the majority of thermal radiation and visible radiation originating from the sun and from the atmosphere, which facilitates cooling of the cooling material **40**. The reflective material may comprise for example Al, Cu, Ag, Au, Ni, Cr, Mo, W or steel including stainless steel.

[0084] In a variation of the embodiment shown in FIG. **4**, the reflective material may not be provided in form of a layer, but may be provided in form of reflective particles that are incorporated in the material **34**.

[0085] For example, the cooling material **40** may form a part of a roof tile or sheet or any other suitable object such as a component of a heat exchanger. The reflective material **42** may comprise a metallic portion of a roof sheet to which the polymeric material **34** incorporating the particles **24** and **36** is applied.

[0086] Referring now to FIG. **5**, a cooling material **50** according to a fourth specific embodiment of the present invention is now described. Again, the cooling material **50** comprises in this embodiment particles **24** and **36** which are incorporated in a polymeric matrix material **34** that is of the same type as described above. In this embodiment, however, the polymeric maternal **34** with particles **24** and **36** is positioned on a layer **52** that is composed of a spectrally selective material. For example, the layer **52** may comprise SiO that is arranged to emit radiation at a wavelength within the atmospheric window wavelength range, which facilitates cooling of the cooling material **50**. The layer **52** typically is largely transparent at other wavelength ranges. Alternatively, the layer **52** may also comprise another suitable spectrally selective material.

[0087] The cooling material **50** is in this embodiment largely transparent for visible light, but may also comprise further layers that affect the transmission of light such as dielectric layers that influence the color of transmitted light.

[0088] FIG. **6** shows a cooling material **60** that is related to the cooling material **50** shown in FIG. **5** and described above. The cooling material **60** comprises the particles **24**, the particles **36**, the polymeric material **34** and the spectrally selective layer **52**. The spectrally selective layer **52** is positioned on a reflective material **62** which has properties and a composition similar to that of layer **42** shown in FIG. **4** and described above.

[0089] Similar to the cooling material **40**, the cooling material **60** may also be used for cooling of objects and may form a part of an object, such as a roof tile or part of a heat exchanger or any other suitable object.

[0090] Referring now to FIG. **7**, a cooling material **70** according to a sixth specific embodiment of the present invention is now described. In this embodiment the cooling material **70** comprises particles **72** that may be provided in the form of the above-described particles **24** or particles **36**. The particles **72** are incorporated into the polymeric matrix material **34**. The polymeric matrix material **34** with particles **72** is positioned on a layer **52**, which is described above in the context of FIGS. **5** and **6**. The spectrally selective properties of the particles **72** and those of the layer **52** are selected so that together a desired spectral effect is achieved. The cooling material **70** may also comprise a reflective material, such as reflective material **42** described above which the layer **52** may be positioned.

[0091] It is to be appreciated that in variations of the above-described embodiments the cooling material may not necessarily comprise particles that are arranged for emission of thermal radiation having a wavelength within the atmospheric window wavelength range, but the particles may be replaced by at least one layer, such as a multi-layered structure, that is arranged for emission of thermal radiation having a wavelength within the atmospheric window wavelength range. The layers of the multi-layered structure typically have thicknesses and internal or surface structure that are selected so that in use ionic surface plasmon resonances are generated and the ionic surface plasmon resonances have a wavelength or wavelength range within the atmospheric window wavelength range. For example, the multi-layered structure may comprise SiO and SiC layers having a thickness of the order of 50-150 nm. Alternatively, the particles may be replaced by grains of a layer having a granular structure, such as a suitable SiC layer. In this case the average diameter of the grains is selected so that the layer is arranged for emission of thermal radiation having a wavelength within the atmospheric window wavelength range. The particles may also be replaced by a porous layer or a layer having a rough surface such as a suitable SiC layer. In this case an average pore spacing or a surface profile, respectively, is selected so that the layer is arranged for emission of thermal radiation having a wavelength within the atmospheric window wavelength range. If the cooling material comprises the at least one layer arranged for emission of thermal radiation having a wavelength within the atmospheric window wavelength range, the cooling material may or may not comprise the second spectrally selective component.

[0092] In addition, it is to be appreciated that the cooling material may comprise the above-described particles in addition to the above-described at least one layer. The at least one layer and the particles may both be arranged for emission of thermal radiation having a wavelength range within the atmospheric window wavelength range.

[0093] Although the invention has been described with reference to particular examples, it will be appreciated by those skilled in the art that the invention may be embodied in many other forms. For example, It is to be appreciated that in further variations of the above-described embodiments the particles **24** and the particles **36** or the particles **24** and the layer **52**, or the particles **36** and the layer **52** may also be positioned directly on a surface without being embedded in a polymeric matrix. Further, the cooling material may form a part of any suitable object.

1. A cooling material which comprises:

a first spectrally selective component comprising particles arranged for emission of radiation predominantly having a wavelength or wavelength range within an atmospheric window wavelength range in which the atmosphere of the earth has a reduced average absorption and emission compared with an average absorption and emission in an adjacent wavelength range whereby the cooling material is arranged for emission of thermal radiation and absorption of radiation from the atmosphere within that wavelength range is reduced; and

a second spectrally selective component having a property that distinguishes the second spectrally selective component from the first spectrally selective component and facilitates at least one desired function of the cooling material.

2. The cooling material of claim **1** wherein the second spectrally selective component is arranged to facilitate cooling of the cooling material.

3. The cooling material of claim **1** or **2** wherein the second spectrally selective component is arranged for emission of radiation by a physical process that is identical to that associated with the emission of radiation by the particles of the first spectrally selective components but at a wavelength or wavelength range that differs from that of the first spectrally selective component.

4. The cooling material of claim **1** or **2** wherein the second spectrally selective component is arranged for emission of radiation by a physical process that differs to that associated with the emission of radiation by the particles of the first spectrally selective component.

5. The cooling material of claim **1** or **2** wherein the second spectrally selective component is arranged for absorption of radiation.

6. The cooling material of any one of the preceding claims wherein the particles of the first spectrally selective component are arranged for generation of ionic surface plasmon resonances having a wavelength or wavelength range within the atmospheric window wavelength range.

7. The cooling material of claim **6** wherein the particles of the first spectrally selective component are arranged so that at least some of the ionic surface plasmons have a wavelength within at least one of the wavelength range from 1-7 μm, 2-6 μm and 3-5 μm; and/or at least one of 5-16 μm, 7-14 μm, 8-13 μm and 7.9-13 μm.

8. The cooling material of claim **6** or **7** wherein the particles of the first spectrally selective component are arranged so that the ionic surface plasmons are generated at a wavelength range that is partially outside the atmospheric window wavelength range.

9. The cooling material of any one of the preceding claims wherein the particles of the first spectrally selective component comprise SiC.

10. The cooling material of any one of claims **1**-**5** wherein the particles of the first spectrally selective component are arranged for emission of radiation by a physical mechanisms other than that associated with the generation of ionic surface plasmons.

11. The cooling material of claim **10** wherein the particles of the first spectrally selective component comprise SiO or silicon oxynitride.

12. The cooling material of any one of the preceding claims wherein the second spectrally selective component comprise particles.

13. The cooling material of claim **12** wherein the particles of the first spectrally selective component and the particles of the second spectrally selective component are dispersed within another component.

14. The cooling material of claim **12** or **13** wherein the particles of the second spectrally selective component are arranged for emission of radiation having a wavelength within the atmospheric window wavelength range.

15. The cooling material of any one of claims **12** to **14** wherein the particles of the second spectrally selective component are arranged for emission of radiation by generation of ionic surface plasmons.

16. The cooling material of claim **12** or **13** wherein the particles of the second spectrally selective component are arranged for emission of radiation by a physical mechanisms other than that associated with the generation of ionic surface plasmons.

17. The cooling material of claim **16** wherein the particles of the second spectrally selective component comprise SiO or silicon oxynitride.

18. The cooling material of claim **16** wherein the particles of the second spectrally selective component are arranged for absorbing radiation by generating electronic surface plasmons.

19. The cooling material of any one of claims **1** to **11** wherein the second spectrally selective component comprises a layer.

20. The cooling material of any one of the preceding claims comprising a polymeric material that is transmissive for radiation of a predetermined range.

21. The cooling material of claim **20** wherein at least a portion of the cooling material is of a clear appearance.

22. The cooling material of claim **20** wherein the cooling material is of an opaque appearance.

23. The cooling material of claim **19** wherein the particles of the first spectrally selective component are be embedded in or positioned adjacent the layer.

24. The cooling material as claimed in any one of claims **1** to **20** or claim **23** wherein the cooling material is arranged to reflect at least some incident radiation.

25. The cooling material of claim **24** comprising a reflective layer.

26. The cooling material of claim **24** comprising reflective particles that are dispersed within an at least partially transparent material.

27. The cooling material of any one of claims **24** to **26** wherein the cooling material is arranged so that the majority of incident radiation is reflected.

28. The cooling material of any one of claims **24** to **26** wherein the cooling material also reflects incident radiation having a wavelength within the atmospheric window wavelength range.

29. The cooling material of claim **1** wherein the particles of the first spectrally selective component are arranged for generation of ionic surface plasmons and the second spectrally selective component comprises particles that are also arranged for generation of ionic surface plasmons at a wavelength or wavelength range that differs from that of the particles of the first spectrally selective component.

30. The cooling material of claim **1** wherein the particles of the first spectrally selective component are arranged for generation of ionic surface plasmons and the second spectrally selective component comprises particles that are arranged for generation of electronic surface plasmons.

31. The cooling material of claim **30** wherein the second spectrally selective component comprises particles that are arranged for generation of electronic surface plasmons by absorption of radiation in the near infrared (NIR) wavelength.

32. The cooling material of claim **31** wherein the cooling material is arranged so that a portion of the thermal energy, that is present as a consequence of the absorbed solar radiation in the infrared (NIR) wavelength range, is emitted by the particles of the first spectrally selective component.

33. The cooling material of claim **30** wherein the second spectrally selective component is arranged for generation of electronic surface plasmons having wavelengths at or near the visible wavelength range.

34. The cooling material of any one of the preceding claims comprising a layered structure that is arranged to reflect thermal radiation from the atmosphere or a portion of visible light.

35. A cooling material which comprises:

a spectrally selective component comprising at least one layer arranged for receiving thermal energy and emitting at least a portion of the received thermal energy in the form of the thermal radiation, the thermal radiation predominantly having a wavelength or wavelength range within an atmospheric window wavelength range in which the atmosphere of the Earth has a reduced average absorption and emission compared with an average absorption and emission in an adjacent wavelength range whereby absorption of radiation from the atmosphere is reduced.

36. The cooling material of claim **35** wherein the spectrally selective component is a first spectrally selective component, the cooling material further comprising a second spectrally selective component having a property that distinguishes the second spectrally selective component from the first spectrally selective component and facilitates at least one desired function of the cooling material.

37. The cooling material of claim **35** or **36** wherein the second spectrally selective component is arranged to facilitate cooling of the cooling material.

38. The cooling material of any one of claims **35** to **37** wherein the atmospheric window wavelength range is a wavelength range from 3 to 5 μm and/or from 7.9 μm to 13 μm.

39. The cooling material of any one of claims **35** to **38** wherein the at least one layer is arranged for generation of ionic surface plasmon resonances having a wavelength or wavelength range within the atmospheric window wavelength range.

40. The cooling material of any one of claims **35** to **39** wherein the at least one layer has a structural property that is selected so that the at least one layer is arranged for generation of ionic surface plasmon resonances having a wavelength or wavelength range within the atmospheric window wavelength range.

41. The cooling material of claim **40** wherein the at least one layer comprises grains and wherein the structural property is associated with a diameter of the grains and the grain diameter is selected so that the at least one layer is arranged for generation of ionic surface plasmon resonances having a wavelength or wavelength range within the atmospheric window wavelength range.

42. The cooling material of claim **40** wherein the at least one layer comprises pores and wherein the structural property is associated with a thickness of residual solid the between the pores and wherein the thickness of the residual solid between the pores is selected so that the at least one layer is arranged for generation of ionic surface plasmon resonances having a wavelength or wavelength range within the atmospheric window wavelength range.

43. The cooling material of claim **40** wherein the at least one layer has a surface roughness and wherein the structural property is associated with a thickness or width of surface features of the surface of the at least one layer and wherein the thickness or width of the surface features is selected so that the at least one layer is arranged for generation of ionic surface plasmon resonances having a wavelength or wavelength range within the atmospheric window wavelength range.

44. The cooling material of claim **40** wherein the at least one layer is a part of a multi-layered structure having layer thicknesses that are selected so that the multi-layered structure is arranged for generation of ionic surface plasmon resonances having a wavelength or wavelength range within the atmospheric window wavelength range.

45. A method of cooling using a cooling material for emission of thermal energy, the cooling material comprising a first spectrally selective component and a second spectrally selective component, the second spectrally selective component having a property that distinguishes the second spectrally selective component from the first spectrally selective component, the method comprising:

emitting a portion of the thermal energy from the first spectrally selective component in the form of radiation having a wavelength within the atmospheric window wavelength range in which the atmosphere of the earth has low or negligible average absorption and emission compared with the average absorption and emission in an adjacent wavelength range; and

emitting a portion of the thermal energy from the second spectrally selective component.

46. The method of claim **45** wherein the first spectrally selective component comprises particles arranged for emitting a portion of the thermal energy in the form of radiation having a wavelength within the atmospheric window wavelength range.

47. The method of claim **45** wherein the first spectrally selective component comprises at least one layer arranged for emitting a portion of the thermal energy in the form of radiation having a wavelength within the atmospheric window wavelength range.

48. The method of any one of claims **45** to **47** wherein emitting a portion of the thermal energy from the second spectrally selective component comprises emitting radiation by a physical process that is identical to that associated with the emission of radiation by the first spectrally selective component, but at a wavelength or wavelength range that differs from that of the first spectrally selective component.

49. The method of any one of claims **45** to **47** wherein emitting a portion of the thermal energy from the second spectrally selective component comprises emitting radiation by a physical process that differs to that associated with the emission of radiation by the first spectrally selective component.

50. The method of any one of claims **45**-**49** wherein emitting a portion of the thermal energy from the first spectrally selective component comprises generating ionic surface plasmon resonances having a wavelength or wavelength range within the atmospheric window wavelength range.

51. The method of claim **50** wherein emitting a portion of the thermal energy from the first spectrally selective component is conducted so that at least some of the ionic surface plasmons have a wavelength within at least one of the wavelength range from 1-7 μm, 2-6 μm and 3-5 μm; and/or within at least one of 5-16 μm, 7-14 μm, 8-13 μm and 7.9-13 μm.

52. The method of any one of claims **45** to **49** wherein emitting a portion of the thermal energy from the first spectrally selective component comprises generating the ionic surface plasmons at a wavelength range that is partially outside the atmospheric window wavelength range.

53. The method of any one of claims **45** to **52** wherein emitting a portion of the thermal energy from the second spectrally selective component comprises emitting radiation having a wavelength within the atmospheric window wavelength range.

54. The method of claim **48** wherein emitting a portion of the thermal energy from the second spectrally selective component comprises emitting radiation by generation of ionic surface plasmons.

55. The method of any one of claim **49** wherein emitting a portion of the thermal energy from the second spectrally selective component comprises absorbing radiation by generating electronic surface plasmons.

56. The method of any one of claims **48** to **55** comprising reflecting at least some incident radiation.

57. The method of claim **56** comprising reflecting incident radiation having a wavelength within the atmospheric window wavelength range.

58. The method of any one of claims **45** to **57** comprising controlling at least one of the composition of the first spectrally selective component and a structural property of the first spectrally selective component to control the wavelength range of ionic surface plasmons.

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