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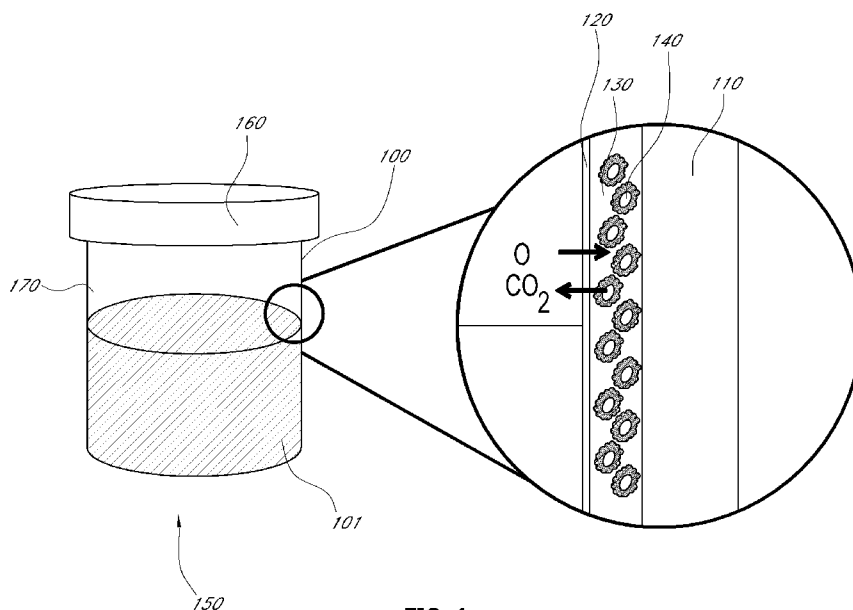


FIG. 1

(57) Abstract: Provided herein are packaging materials that include a bioactive material, as well as methods of using and methods of making such bioactive packaging material. In some embodiments, a packaging material is provided. The material can include an outer layer that is effectively impermeable to oxygen, an inner layer that is effectively permeable to oxygen, and a bioactive material. In some embodiments, the bioactive material is located between the inner layer and the outer layer, and the bioactive layer includes at least one microorganism.



BIOACTIVE PACKAGING

Field

[0001] Embodiments herein generally relate to bioactive packaging materials, methods of making bioactive packaging materials, and uses of bioactive packaging materials.

Background

[0002] There are a variety of packaging materials that can be used to store food and other materials in order to, for example, preserve and/or protect the material so stored. Generally, these materials attempt to preserve food by isolating the material from external sources of contamination, such as microorganisms.

SUMMARY

[0003] In some embodiments, a packaging material is provided. The material can include an outer layer that is effectively impermeable to oxygen, an inner layer that is effectively permeable to oxygen, and a bioactive material. In some embodiments, the bioactive material is located between the inner layer and the outer layer, and the bioactive layer includes at least one microorganism.

[0004] In some embodiments, a method of containing an item is provided. The method can include providing a packaging material that includes an outer layer that is effectively impermeable to oxygen, an inner layer that is permeable to oxygen, and a bioactive material. In some embodiments, the bioactive material is located between the inner layer and the outer layer, and the bioactive layer includes at least one microorganism. In some embodiments, the method further includes exposing an item to the packaging material. In some embodiments, a surface of the inner layer faces a surface of the item to contain the item.

[0005] In some embodiments, a method of making a packaging material is provided. The method can include providing an outer layer that is substantially impermeable to oxygen, providing a bioactive material, and providing an inner layer. In some embodiments, the inner layer is permeable to oxygen, and the bioactive material is

positioned between the outer layer and the inner layer, thereby making a packaging material.

[0006] The foregoing summary is illustrative only and is not intended to be in any way limiting. In addition to the illustrative aspects, embodiments, and features described above, further aspects, embodiments, and features will become apparent by reference to the drawings and the following detailed description.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] **Figure 1** is a drawing of some embodiments of a packaging material.

[0008] **Figure 2** is a flow chart outlining some embodiments of a method of containing an item.

[0009] **Figure 3** is a flow chart outlining some embodiments of a method of making a packaging material.

DETAILED DESCRIPTION

[0010] In the following detailed description, reference is made to the accompanying drawings, which form a part hereof. In the drawings, similar symbols typically identify similar components, unless context dictates otherwise. The illustrative embodiments described in the detailed description, drawings, and claims are not meant to be limiting. Other embodiments may be utilized, and other changes may be made, without departing from the spirit or scope of the subject matter presented herein. It will be readily understood that the aspects of the present disclosure, as generally described herein, and illustrated in the Figures, can be arranged, substituted, combined, separated, and designed in a wide variety of different configurations, all of which are explicitly contemplated herein.

[0011] In some embodiments, a bioactive packaging material is provided. In some embodiments, the bioactive packing material includes one or more microorganisms. In some embodiments, the microorganism can be embedded in a matrix that is part of the packaging material. In some embodiments, the microorganism is initially in a metabolically quiescent state, but can become activated as an item that is stored in the packaging material decomposes. In some embodiments, as the item incubates or decomposes, and/or after the packaging is opened, the amount of oxygen inside the packaging increases. In some embodiments, the presence of additional oxygen activates

the microorganism, thereby removing it from the metabolically quiescent state. In some embodiments, the microorganism scavenges oxygen, thus decreasing the amount of oxygen in the packaging and preserving the shelf life of the item stored within the packaging material. In some embodiments, the microorganism produces molecules that prolong the shelf life of the item to be stored. These and other embodiments are discussed in more detail below.

[0012] Figure 1 is a drawing that illustrates some embodiments of a packaging material 100. In some embodiments, the packaging material includes an outer layer 110. In some embodiments, the packaging material includes an inner layer 120. In some embodiments, the packaging material includes a bioactive material 130. In some embodiments, the bioactive material is part of and/or within the inner layer. In some embodiments, the bioactive material is between the inner layer 120 and the outer layer 110 (as depicted in Figure 1). In some embodiments, the bioactive material includes one or more microorganisms 140. While the packaging material is depicted as a storage container 150, in some embodiments, other configurations and applications are also possible (discussed in more detail below). In some embodiments, the packaging material has a lid 160. In some embodiments, the lid 160 forms an airtight seal with the storage container 150. In some embodiments, the storage container 150, when an item 101 is placed in it, includes a headspace 170.

[0013] A variety of outer layers can be employed. In some embodiments, the outer layer is effectively impermeable to liquid. In some embodiments, the outer layer effectively prevents 50, 60, 70, 80, 90, 95, 96, 97, 98, 99, 99.9, 99.99, 99.999% or more of a liquid from passing through it. In some embodiments, the outer layer is effectively impermeable to gas. In some embodiments, the outer layer effectively prevents 10, 20, 30, 40, 50, 60, 70, 80, 90, 95, 96, 97, 98, 99, 99.9, 99.99, 99.999, 99.9999, 99.99999% or more of a gas from passing through it. In some embodiments, the gas is oxygen. In some embodiments, the outer layer limits diffusion of oxygen. In some embodiments, the outer layer limits diffusion of oxygen across it so that at a temperature range of -50°C to 150°C, there is a first partial pressure of oxygen on one side of the outer layer, which is different from a second the partial pressure of oxygen on the other side of the outer layer, and after 24 hours have passed, at least about 80% of that difference in partial pressure of oxygen still exists. In some embodiments, the outer layer effectively prevents an amount of oxygen from passing through it that would be enough to activate the microorganisms in

the packaging material. In some embodiments, the outer layer provides an effectively airtight barrier over the period of time for which the packaging material is to be used to store an item (which can be, for example, hours, days, weeks, months, or years).

[0014] In some embodiments, the outer layer is at least about 0.001 millimeters thick, e.g., 0.001, 0.002, 0.005, 0.01, 0.03, 0.05, 0.10, 0.15, 0.2, 0.5, 1, 2, 3, 5, 10, 15, 20, 30, 50, 80, 100, or 200 millimeters thick, including any range defined between any two of the stated values and any range above any one of the stated values.

[0015] In some embodiments, the outer layer includes a polymer. In some embodiments, the outer layer is biodegradable. In some embodiments, the outer layer can include plastic, metal, and/or glass.

[0016] In some embodiments, the packaging material includes an inner layer; however, the inner layer can be optional. In some embodiments, the inner layer is effectively permeable to gas. In some embodiments, the gas is oxygen, carbon dioxide, or both oxygen and carbon dioxide. In some embodiments, the inner layer is permeable to one or more of the following: an antimicrobial compound, a preservative, a flavor modifier, an odor molecule. In some embodiments, the inner layer is simply part of, or is, a matrix, which can contain the microorganisms. In some embodiments, the inner layer includes a polymer. In some embodiments, the inner layer includes a film. In some embodiments, the inner layer is a polymer film. In some embodiments, the polymer film includes a homopolymer. In some embodiments, the polymer includes a heteropolymer. In some embodiments, polymer film includes a plastic polymer and/or a cellulose polymer. In some embodiments the inner layer includes an insert, for example a plastic, cardboard, various polymers, PVDF, waxes, lipids, silicates rubber, and/or cellulose. In some embodiments, the insert contacts the matrix. In some embodiments, the insert is covalently bonded to at least a part of the matrix. In some embodiments, the insert is positioned further than 0.5 micrometers from the matrix, e.g., 1, 2, 3, 5, 10, 15, 20, 30, 50, 80, 100, 150, 200, 250, 300, 400, 500, 700, 900, 1000, 1500, 2000, 3000, or 5000 micrometers from the matrix, but does not contact the matrix (including any range above any one of the preceding values and any range defined between any two of the preceding values).

[0017] In some embodiments, the inner layer has a thickness of at least about 0.5 micrometers, e.g., 0.5, 1, 2, 3, 5, 10, 15, 20, 30, 50, 80, 100, 150, 200, 250, 300, 400, 500, 700, 900, 1000, 1500, 2000, 3000, 5,000, 10,000, or 100,000 micrometers, including

any range above any one of the preceding values and any range defined between any two of the preceding values. In some embodiments, the inner layer is opaque. In some embodiments, the inner layer is transparent. In some embodiments, the inner layer contains perforations or pores. In some embodiments the perforations or pores have diameters of at least about 0.1 micrometer, e.g., 0.1, 0.3, 0.7, 1, 2, 3, 5, 10, 15, 20, 30, 50, 80, 100, 150, 200, 250, 300, 400, 500, 700, 900, 1000, 1500, 2000, or 3000 micrometers, including any range above any one of the preceding values and any range defined between any two of the preceding values. In some embodiments, the perforations or pores have substantially uniform diameters. In some embodiments, the perforations or pores have diameters of two or more substantially different sizes.

[0018] In some embodiments, the packaging material includes a matrix, which, in some embodiments, can be the bioactive layer. In some embodiments, the microorganism contacts and/or is associated with the matrix. In some embodiments, the microorganism is embedded in the matrix. In some embodiments, the microorganism contacts a surface of the matrix. In some embodiments, the matrix is located between the inner layer and the outer layer. In some embodiments, the matrix is, or is part of, the inner layer. In some embodiments, there is no inner layer, and the matrix is exposed to the interior of the packaging material. In some embodiments, the matrix contacts the item or items to be packaged by the packaging material. In some embodiments, the matrix is permeable to gas. In some embodiments, the matrix is permeable to oxygen. In some embodiments, the matrix is permeable to carbon dioxide. In some embodiments, the matrix is a solid. In some embodiments, the matrix is a foam. In some embodiments, the matrix is a gel.

[0019] In some embodiments, the matrix includes a nutrient for the microorganism. In some embodiments, the matrix includes at least one of a starch, a carbohydrate, a polynucleotide, a protein, or a synthetic polymer. In some embodiments, these are included in an amount sufficient for keeping the microorganism alive for a period of time during which the packaging material is to be used, e.g., at least hours, days, weeks, months, or years.

[0020] In some embodiments, the matrix includes a cross-linking agent. In some embodiments, molecules of the matrix are cross-linked. In some embodiments, the matrix includes at least one of a peptide, a casein peptone, a vitamin, for example a B vitamin, nitrogen, sulfur, magnesium, or a mineral, for example an essential mineral.

[0021] In some embodiments, one or more of the components of the matrix is biodegradable. In some embodiments, all or substantially of the ingredients of the matrix are biodegradable.

[0022] In some embodiments, the matrix does not include a bioactive material, such as a microorganism. For example, in some embodiments, an outer layer with a matrix applied to the inside of the outer layer can be provided as a product. At a later point in time, one can add one or more microorganisms to the matrix, allow them to attach to the matrix, and then use the packaging material. Thus, in some embodiments, any of the packaging material embodiments provided can be provided as an “inert” form (without the microorganism), and the microorganism can be added later (e.g., directly to the matrix, to the matrix and crosslinked, directly to an internal surface of the outer layer, directly to the outer surface of an inner layer, etc.) In some embodiments, these items can be provided in the form of a kit.

[0023] In some embodiments, the packaging material includes a bioactive material 130. In some embodiments, the bioactive material 130 is separate from the inner layer 120. In some embodiments, the bioactive material 130 is located between the outer layer 110 and the inner layer 120. In some embodiments, the bioactive material 130 is part of the inner layer (e.g., the bioactive material can be located within and/or on the inner layer). In some embodiments, there is no inner layer, and the bioactive material is exposed to the interior of the packaging material. In some embodiments, there need not be an inner layer and the bioactive material can be exposed to the interior of the packaging material. In such embodiments, the inner surface of that layer can be, for example, crosslinked. In some embodiments, the bioactive material can be included within a matrix. In some embodiments, the bioactive material includes one or more microorganism, e.g., at least 1, 10, 100, 1,000, 10,000, 100,000, 1,000,000, 10,000,000, 100,000,000, 1,000,000,000, 10,000,000,000, 100,000,000,000, or more microorganisms. In some embodiments, the number of microorganisms per cubic centimeter can be determined based upon the particular application. In some embodiments, the number of microorganisms per cubic centimeter can be from 1 to 1×10^{11} cells/mL.

[0024] In some embodiments, the microorganism is in a metabolically quiescent state. In some embodiments, the metabolically quiescent state is a “live but not replicating (LNR)” state. In some embodiments, the LNR state provides reduced replication by the microorganism. In some embodiments, the LNR state includes a

replication rate that is no faster than about 1×10^{-1} , 5×10^{-1} , 1×10^{-2} , 1×10^{-3} , 1×10^{-4} , 1×10^{-5} , or 1×10^{-6} of the replication rate of the microorganism cultivated on rich medium in a normal, non-metabolically quiescent state. In some embodiments the replication rate is effectively zero. In some embodiments, the metabolically quiescent state includes a state of nutrient deprivation. In some embodiments, the metabolically quiescent state is “metabolic hibernation.” In some embodiments, the metabolically quiescent state is reversible so that the microorganism will exit the metabolically quiescent state and return to metabolically active state. In some embodiments, a substance secreted by the packaged item induces the microorganism to exit the metabolically quiescent state. In some embodiments, oxygen induces the microorganism to exit the metabolically quiescent state. In some embodiments, the microorganism is genetically modified to enter a quiescent state. For example, in some embodiments the microorganism contains a mutation in a regulator of the cell cycle or metabolic enzyme that reduces the growth rate of the bacterium. Furthermore, in some embodiments, the microorganism optionally includes an inducible transgene that restores normal cell cycle regulation or metabolism in the presence of a desired molecule, for example oxygen. In some embodiments, a Tet ON/OFF system can be used. For example, in the presence of Tetracycline (for example in a Tet OFF system), the transgene of interest is repressed. This can be used, to switch the microorganisms in the matrix “on” when the tetracycline in the food is depleted and/or destroyed. This can be used, for example, as a second line antibacterial defense by having the microorganisms in the packaging produce bacteriocins in the absence of the antibiotic.

[0025] In some embodiments, the microorganism is aerobic. In some embodiments, the microorganism is aerobic, and the metabolically quiescent state includes oxygen deprivation. In some embodiments, the microorganism scavenges oxygen. In some embodiments, the microorganism secretes one or more substances. In some embodiments, the microorganism scavenges oxygen and secretes one or more substances.

[0026] In some embodiments the microorganism is prokaryotic. In some embodiments, the microorganism is a bacterium. In some embodiments, the microorganism is eukaryotic. In some embodiments, the microorganism is a fungus. In some embodiments, the microorganism is a yeast. In some embodiments, a mixture of microorganisms of two or more types is used. In some embodiments, the microorganism is one that is Generally Recognized As Safe (GRAS) in the United States, Australia,

Europe, and/or Japan. In some embodiments, the microorganism can include one or more of Lactic acid bacteria (LAB), bifidobacteria, yeast, bacilli, *Bacillus coagulans*, *Lactobacillus acidophilus*, *Lactobacillus casei*, *Lactobacillus casei*, Shirota, non-pathogenic microorganisms, bacteria, *Acetobacter*, *Acholeplasma laidlawii*, *Acidovorax*, *Actinoalloteichus*, *Actinosynnema mirum*, *Aeromicrobium*, *Agrobacterium tumefaciens*, *Lactobacillus casei*, *Alicyclobacillus*, *Alishewanella*, *Aneurinibacillus*, *Aquabacterium commune*, *Aquabacterium citratiphilum*, *Aquabacterium parvum*, *Aquaspirillum itersonii*, *Aquifex aeolicus*, *Aquifex pyrophilus*, *Arthrobacter globiformis*, *Azomonas macrocytogenes*, *Bacillus agri*, *Bacillus alginolyticus*, *Bacillus aneurinolyticus*, *Bacillus azotoformans*, *Bacillus atrophaeus*, *Bacillus badius*, *Bacillus borstelensis*, *Bacillus centrosporus*, *Bacillus chondroitinus*, *Bacillus choshinensis*, *Bacillus circulans*, *Bacillus coagulans*, *Bacillus cohnii*, *Bacillus formosus*, *Bacillus galactophilus*, *Bacillus globisporus*, *Bacillus halodurans*, *Bacillus laevolacticus*, *Bacillus licheniformis*, *Bacillus megaterium*, *Bacillus methanolicus*, *Bacillus migulanus*, *Bacillus mojavenensis*, *Bacillus mycoides*, *Bacillus naganoensis*, *Bacillus pallidus*, *Bacillus parabrevis*, *Bacillus polymyxa*, *Bacillus pumilus*, *Bacillus reuszeri*, *Bacillus sphaericus*, *Bacillus stearothermophilus*, *Bacillus subtilis*, *Bacillus thermocloacae*, *Bacillus thuringiensis*, *Blastomonas*, *Brachybacterium*, *Brochothrix*, *Brevibacillus*, *Brevibacterium*, *Brevundimonas vesicularis*, *Budvicia aquatica*, *Buttiauxella agrestis*, *Butyrivibrio crossotus*, *Carnobacterium*, *Carnobacterium divergens*, *Caulobacter*, *Cellulomonas*, *Cellulomonas cellulans*, *Clostridium butyricum*, *Clostridium tertium*, *Clostridium tetanomorphum*, *Collinsella intestinalis*, *Collinsella* spp, *Collinsella stercoris*, *Comomonas acidovorans*, *Corynebacterium accolens*, *Corynebacterium afermentans*, *Corynebacterium argentoratense*, *Corynebacterium auris*, *Corynebacterium genitalium*, *Corynebacterium propinquum*, *Corynebacterium pseudodiphtheriticum*, *Corynebacterium macginleyi*, *Corynebacterium tuberculostearicum*, *Corynebacterium urealyticum*, *Curtobacterium*, *Deinococcus* spp, *Delftia*, *Dermacoccus nishinomiyaensis*, *Desemzia*, *Dietzia*, *Dysgonomonas*, *Empedobacter*, *Enterobacter agglomerans*, *Enterococcus avium*, *Enterococcus durans*, *Enterococcus porcinus*, *Enterococcus ratti*, *Erwinia*, *Escherichia blattae*, *Exiguobacterium*, *Fibrobacter*, *Filifactor*, *Finegoldia*, *Flavobacterium capsulatum*, *Flavobacterium columnare*, *Flavobacterium psychrophilum*, *Fusobacterium prausnitzii*, *Geotrichium candidum*, *Gluconobacter*, *Glycomyces tenuis*, *Gracilibacillus*, *Granulicatella*, *Haemophilus paragallinarum*, *Haemophilus parasuis*, *Haemophilus*

somnus, *Halobacterium salinarium*, *Helicobacter hepaticus*, *Helicobacter muridarum*, *Holdemania*, *Intrasporangium calvum*, *Klebsiella terrigena*, *Kocuria*, *Kocuria rosea*, *Kurthia gibsonii*, *Kytococcus*, *Lactobacillus delbrueckii*, *Lactobacillus fermentum*, *Lactobacillus leichmannii*, *Lactobacillus oris*, *Lactobacillus plantarum*, *Lactobacillus vaginalis*, *Lactococcus garvieae*, *Lactococcus lacti*, *Lautropia*, *Lawsonia*, *Lechevaliera*, *Leifsonia*, *Lentzia*, *Leptospira biflexa*, *Leuconostoc*, *Listeria innocua*, *Listeria ivanovii*, *Listeria welshimeri*, *Luteococcus*, *Macrococcus*, *Mannheimia*, *Maricaulis*, *Megamonas*, *Methylobacterium amnivorans*, *Methylobacterium mesophilicum*, *Micrococcus diversus*, *Mycoplasma gallisepticum*, *Micrococcus luteus*, *Micrococcus roseus*, *Micromonas*, *Micromonospora coerulea*, *Moraxella bovis*, *Mortierella wolfii*, *Mucor hiemalis*, *Mycoplasma bovigenitalium*, *Mycoplasma hyopneumoniae*, *Mycoplasma hyorhinis*, *Mycoplasma iowae*, *Mycoplasma synoviae*, *Mycoplasma orale*, *Nesterenkonia*, *Obesumbacterium proteus*, *Oerskovia*, *Oligella ureolytica*, *Ornithobacterium*, *Paenibacillus*, *Paracoccus*, *Penicillium expansum*, *Penicillium verrucosum*, *Pentatrichomonas hominis*, *Planobispora rosea*, *Porphyromonas endodontalis*, *Porphyromonas gulae*, *Pragia fontium*, *Propioniferax*, *Proteus myxofaciens*, *Pseudomonas alcaligenes*, *Pseudomonas diminuta*, *Pseudomonas fluorescens*, *Pseudomonas putida*, *Pseudomonas syringae*, *Renibacterium salmoninarum*, *Ruminococcus*, *Rhodospirillum rubrum*, *Rickenella*, *Ruminococcus productus*, *Saccharothrix longispora*, *Saccharothrix mutabilis*, *Sanguibacter*, *Schineria*, *Sebaldella*, *Shewanella putrefaciens*, *Slackia*, *Solobacterium*, *Sporosarcina ureae*, *Staphylococcus caprae*, *Staphylococcus carnosus*, *Staphylococcus lentus*, *Staphylococcus pulvereri*, *Stomatococcus*, *Streptococcus parauberis*, *Streptomyces albus*, *Streptomyces corchorusii*, *Streptomyces olivaceoviridis*, *Streptomyces scabiei*, *Streptosporangium roseum*, *Taylorella*, *Tatlockia*, *Tetragenococcus halophilus*, *Terracoccus*, *Thermoanaerobacterium thermosaccharolyticum*, *Thermotoga maritime*, *Thermus*, *Tissaracoccus*, *Tritrichomonas foetus*, *Turicella otitidis*, *Ureaplasma diversum*, *Vagococcus fluvialis*, *Vagococcus salmoninarum*, *Xanthomonas campestris*, *Xenorhabdus nematophilus*, *Yersinia ruckeri*, *Zoogloea ramigera*, *Zygosaccharomyces rouxii*, *Fungi*, *Acremonium strictum*, *Aspergillus penicillioides*, *Dactylaria gallopava*, *Galactomyces geotrichum*, *Metschnikowia pulcherrima*, *Neurospora*, *Penicillium notatum*, *Penicillium roquefortii*, *Pentatrichomonas hominis*, *Pichia haplophila*, *Saccharomyces carlsbergensis*, *Saccharomyces pastorianus*, *Schizosaccharomyces*, *Tritrichomonas mobilensis*, *Zygosaccharomyces bailii*, and/or *Zygosaccharomyces rouxii*.

In some embodiments, the organism can be one that is an aerobe that is GRAS, such as *Bacillus subtilis*, that can ferment under some conditions.

[0027] In some embodiments, the microorganism is a probiotic organism that is used as a nutritional supplement. In some embodiments, the number of organisms used, as well as the concentration in the final packaging product will depend on the type of organism chosen, as each can have a somewhat different respiration rate.

[0028] In some embodiments, the microorganism can survive at a temperature of at least 0°C, for example 10, 10, 20, 30, 50, 60, 70, 80, 90, 100, 110, 120, 140, 170, 200, or 250 °C, including ranges between any two of the listed values and any range above any one of the preceding values. In some embodiments, the microorganism can survive at a pressure of at least 100 kilopascals, e.g., 100, 110, 120, 130, 140, 150, 160, 170, 180, 190, 200, 240, 300, 350, 400, or 500 kilopascals, including ranges between any two of the listed values and any range above any one of the preceding values. In some embodiments, the microorganism can survive at high temperature (above room temperature) and high pressure (above atmospheric). In some embodiments the microorganism is a thermophile. In some embodiments, the microorganism is has undergone selection, and/or is genetically modified to facilitate survival at extreme temperature and/or pressure.

[0029] In some embodiments, the microorganism secretes one or more substances. In some embodiments, the microorganism is genetically modified to secrete a substance. In some embodiments, the substance includes a flavor modifier, color modifier, or odor modifier. In some embodiments, the substance can be a pH modifier (for example, an acid or a base), antimicrobial (for example, bacteriocin), texture modifiers (for example, gelatin, proteins, polysaccharide) sweetener (for example, sugar), etc. In some embodiments, the microorganism secretes the substance in response to a condition, for example high oxygen concentration or spoilage of a packaged item. In some embodiments, the secreted substance warns a user, manufacturer, or vendor of a condition of the item. In some embodiments, the secreted substance provides a visual cue. In some embodiments, the visual cue can be observed through the packaging, and thus, one need not open the packaging to observe the cue, when, for example, the packaging is at least partially transparent. In some embodiments, the compounds could include luciferase/luciferin, and/or could be a pigment produced by the microorganisms, such as melanin, or another pigmented protein.

[0030] In some embodiments, the packaging material is opaque. In some embodiments, the packaging material is effectively transparent. In some embodiments, the packaging material is at least about 30%, 50%, 70%, 80%, 90%, 95%, or 99% transparent to visible light, including ranges between any two of the stated values. In some embodiments, at least one layer of the packaging material is opaque, and at least one layer of the packaging material is transparent. For example, in some embodiments the matrix and/or inner layer is opaque, while the outer layer is effectively transparent to permit visual examination of the matrix and/or bioactive material.

[0031] In some embodiments, the outer layer, the inner layer, and/or the matrix provides a rigid wall of the packaging material. In some embodiments, all three of the outer layer, the inner layer, and the matrix together provide a rigid wall. In some embodiments, the outer layer and inner layer provide a rigid wall. In some embodiments, the outer layer and matrix provide a rigid wall. In some embodiments, the inner layer and matrix provide a rigid wall. In some embodiments, at least one of the outer layer, inner layer, or matrix provides a flexible wall, for example a conforming wall that conforms to the item being packaged. In some embodiments, the inner layer and/or matrix provide a conforming wall while the outer layer is rigid. In some embodiments, all three of the inner layer, matrix, and outer layer conform to the item being packaged.

[0032] In some embodiments, the packaging material is in the shape of a container. In some embodiments, the packaging material is in the shape of a free standing storage container. In some embodiments, the storage container is one of a canister, a box, a jar, a bottle, a capsule, a specimen tube, a blister pack, a pouch, a bag, etc.

[0033] In some embodiments, the storage container is a food storage container. In some embodiments, the storage container is an agricultural product storage container, for example, for storing plants, seeds, and/or spores. In some embodiments, the storage container is a biological specimen container. In some embodiments, the storage container is a cell culture container. In some embodiments, the storage container is an organ transport container. In some embodiments, the storage container stores a forensic sample. In some embodiments, the storage container can be (and/or configured) for pharmaceuticals, biologics, film, electronics, paint, various coatings, and/or fast moving consumer goods (FMCG).

[0034] In some embodiments, the storage container has an opening. In some embodiments, the storage container has two or more openings. In some embodiments the

container is, and/or can be sealed, such that it is substantially airtight unless an opening in the material is provide or is opened. In some embodiments, the opening is configured to be closeable and can include with an airtight seal. In some embodiments, the opening is for inserting or removing the item to be packaged. In some embodiments, the opening is a ventilation opening. In some embodiments, the opening has a diameter of about at least about 0.1 cm, e.g., 0.1, 0.5, 1, 2, 3, 5, 8, 10, 12, 15, 20, 25, 30, 40, 50, 60, 80, 100, 150, 200, 250, 300, or 500 cm, included any range between any two of the listed values and any range above any one of the preceding values. In some embodiments the seal is reusable, and the container can undergo multiple cycle of unsealing and re-sealing. In some embodiments, the seal is a single use seal.

[0035] In some embodiments, the container includes a lid. In some embodiments, the lid includes a gasket. In some embodiments, the lid forms an airtight seal with the container.

[0036] In some embodiments, for example when the packaging material is rigid, the storage container seals a substantially fixed volume, which can be defined by the packaging material. In some embodiments, for example when the packaging material is flexible or conforming, the storage container seals a maximum volume, which can be defined by the packaging material. In some embodiments, when the storage container is sealed, it encloses a volume of at least about 0.00001 liters, e.g., 0.00001, 0.0001, 0.001, 0.01, 0.1, 0.3, 0.5, 0.7, 1, 1.3, 1.5, 1.8, 2, 2.5, 3, 4, 5, 7, 10, 15, 20, 50, 100, 200, 300, 500, 1000, 10,000, or 100,000 liters, including ranges between any two of the listed values and any range above any one of the preceding values. In some embodiments, the storage container includes two or more compartments and when the container is sealed, each compartment is substantially impermeable to gas.

[0037] In some embodiments, the opening has a self-sealing closure. In some embodiments, the self-sealing closure is resealable. In some embodiments, the self-sealing closure can be opened and resealed at least 1 time, e.g., about 1, 2, 3, 5, 10, 15, 20, 40, 50, 100, 150, 200, 300, or 500 times, including any range between any two of the preceding values. In some embodiments, the self-sealing closure includes an adhesive. In some embodiments, the adhesive is pressure sensitive. In some embodiments, the self-sealing closure includes a zipper. In some embodiments, the self-sealing closure includes a clasp. In some embodiments, the storage container is a self-sealing bag.

[0038] In some embodiments, a method of containing an item is provided. In some embodiments, one or more item are contained, e.g., 1, 2, 5, 10, 100, 1000, 10,000, 100,000 or more item can be contained within the packaging material. In some embodiments, the method includes providing a packaging material that includes a bioactive material and exposing the item to the packaging material so that an inner surface of the packaging material faces the item.

[0039] Figure 2 is a flow chart that illustrates some embodiments of a method of containing an item 200. In some embodiments, a packaging material that includes an outer layer that is effectively impermeable to gas is provided, along with a bioactive material and (optionally) an inner layer that is effectively permeable to gas 210. In some embodiments, the item is exposed to the packaging material so that an inner surface of the packaging material faces a surface of the item 220. Optionally, in some embodiments, the item can be fully contained within the packaging material 230 for some period of time thereafter.

[0040] One skilled in the art will appreciate that, for this and other processes and methods disclosed herein, the functions performed in the processes and methods may be implemented in differing order. Furthermore, the outlined steps and operations are only provided as examples, and some of the steps and operations may be optional, combined into fewer steps and operations, or expanded into additional steps and operations without detracting from the essence of the disclosed embodiments.

[0041] In some embodiments, the method of containing an item includes providing any of the packaging material embodiments described herein. In some embodiments, the method includes exposing the item to the packaging material, so that an inner surface of the packaging material faces a surface of the item. In some embodiments, a surface of the item is in contact with an inner surface of the packaging material. In some embodiments, the item is not in contact with an inner surface of the packaging material, but gas can diffuse between the item and the inner surface of the packaging material. In some embodiments, the method includes sealing the item within the packaging material. In some embodiments, the method includes wrapping the item in the packaging material. In some embodiments, the method includes spraying the packaging material onto the item (e.g., each layer can be spray applied onto the item, finishing with the outer layer).

[0042] In some embodiments, the method includes positioning the item to be packaged proximal to the inner layer, and positioning the item to be packaged distal to the outer layer. In some embodiments, the method includes positioning the item to be packaged proximally to the bioactive material, and positioning the outer layer distal to the item to be packaged.

[0043] In some embodiments, the item to be packaged is a food product. In some embodiments, the item to be packaged is one of a fruit, a vegetable, a dairy product, a meat product, a baked product, a ready-to-eat item, a beverage, or a combination of the above. In some embodiments, the item to be packaged is an agricultural product, for example a plant, seed, spore, or culture. In some embodiments, the item to be packaged is a cell culture. In some embodiments, the item to be packaged is an organ or tissue, for example for transplant or laboratory analysis. In some embodiments, the item to be packaged is a forensic sample. In some embodiments, the item to be packaged is a pharmaceutical product or any of the other products and/or materials described herein.

[0044] In some embodiments the packaging material is (and/or is part of) a container. In some embodiments, the method includes inserting the item into a container that includes the packaging material. In some embodiments, the method includes assembling the container around the item to be packaged.

[0045] In some embodiments, the method includes sealing the container. In some embodiments, the item to be packaged is sealed inside of the container. In some embodiments, sealing includes applying pressure to a pressure-sensitive adhesive. In some embodiments, sealing includes closing a zipper closure. In some embodiments, sealing includes closing a clasp. In some embodiments, sealing includes applying a lid, and securing the lid, for example with friction, with a screw, with a clasp, with a strap, with a sealant, and/or with a tape. In some embodiments, sealing includes applying a substantially airtight seal. In some embodiments, the lid, zipper closure, and/or adhesive closure forms an airtight seal when it contacts the container. In some embodiments, applying the airtight seal includes contacting the lid or closure with a gasket. In some embodiments, applying the airtight seal includes applying a sealant, for example a gel, putty, foam, paste, tape, and/or film. In some embodiments, the sealant includes an adhesive. In some embodiments, after sealing, the container is reopened and then resealed. In some embodiments, multiple cycles of opening and re-sealing are performed.

[0046] In some embodiments, the method includes sealing the container so that there is a headspace volume between the item to be packaged and the inner surface of the container (see Figure 1, 170). In some embodiments, gas effectively flows between the item and the headspace. In some embodiments, the headspace volume is at least about 0.1 percent of the volume of the container, e.g., 0.1, 0.2, 0.3, 0.5, 1, 1.5, 2, 3, 5, 10, 15, 20, 30, 50, 60, 70, 80, 90, 95, 99, 99.9 percent, including ranges between any two of the listed values and any range below any one of the preceding values.

[0047] In some embodiments, immediately after the item is sealed in the container, the headspace volume contains some amount, e.g., a particular percentage content, of oxygen. In some embodiments, 2 hours after the item is sealed in the container, the percentage content of oxygen in the headspace decreases, and/or the percent content of carbon-dioxide increases. In some embodiments, the percentage content of oxygen decreases at least about 1%, 3%, 5%, 10%, 20%, 30%, 50%, 60%, 70%, 80%, 90%, 95%, 98%, 99% or more in comparison to the amount present at the time the item was sealed in the container, including ranges between any two of the listed values. In some embodiments, the percentage content of carbon dioxide increases at least about 1%, 3%, 5%, 10%, 20%, 30%, 50%, 60%, 70%, 80%, 90%, 95%, 98%, 99% or more in comparison to the amount present at the time the item was sealed in the container, including ranges between any two of the listed values.

[0048] In some embodiments, the method allows gas to travel between the headspace 170 to the bioactive material 130 (Figure 1). In some embodiments, this occurs by gas diffusing between the headspace and the bioactive material. In some embodiments, for example when the inner layer is present, gas travels through the inner layer to arrive at the bioactive material, for example by diffusion. In some embodiments, the gas includes oxygen. In some embodiments, the microorganism in the bioactive material is in a metabolically quiescent state prior to being contacted with oxygen, and contact with oxygen induces the microorganism to enter a metabolically active state, thereby allowing the microorganism to convert oxygen to CO₂.

[0049] In some embodiments, microorganism of the bioactive material metabolizes the oxygen that is present in the container and the microorganism exchanges the oxygen for carbon dioxide. In some embodiments, the carbon dioxide travels from the bioactive material to the headspace. In some embodiments, for example when the inner layer is present, the carbon dioxide travels through the inner layer, for example by

diffusion. Thus, the exchange by the microorganisms of oxygen for carbon dioxide reduces the percentage content of oxygen in the headspace. In some embodiments, the microorganism metabolizes oxygen, and incorporate the oxygen into a non-elemental oxygen molecule, for example water.

[0050] In some embodiments, any of the above methods can be used for increasing and/or preserving various items, such as food, pharmaceutical products, etc. In some embodiments, any of the above methods do not need to increase the shelf life of an item, but instead (or in addition to) can provide a method for providing a flavor modifier, a color modifier, and/or odor modifier. In some embodiments, any of the above methods do not need to increase the shelf life of an item, but instead (or in addition to) can provide a method for warning a user, manufacturer, and/or vendor of a condition of the item. In some embodiments, a secreted substance from the bioactive material provides a visual cue. In some embodiments, the visual cue can be observed through the packaging, and thus, one need not open the packaging to observe the cue, when, for example, the packaging is at least partially transparent.

[0051] In some embodiments, a method of making a packaging material is provided. In some embodiments, the method includes providing a bioactive material. In some embodiments, the method includes providing an outer layer that is substantially impermeable to gas and associating the bioactive material with the outer layer, either directly or indirectly.

[0052] Figure 3 is a flow chart that depicts some embodiments of a method of making a packaging material. In some embodiments, an outer layer that is effectively impermeable to gas is provided 300 and a bioactive material can then be provided 310 and associated with the outer layer. In some embodiments, an inner layer that is effectively permeable to gas can, optionally, be provided 320. In some embodiments, the inner layer is positioned so as to keep various items in the container or packaging material separated from the bioactive material, but to still allow gas and/or other substances to pass to and from the bioactive material. In some embodiments, the bioactive material can be associated with an inner surface of the outer layer, or another layer associated with the outer layer 330. In some embodiments, the bioactive layer is placed directly onto the inner surface of the outer layer. In some embodiments, the bioactive layer is placed directly on the inner layer, and the inner layer is placed adjacent to, and therefore associated with, the inner surface of the outer layer. In some embodiments, the outer layer

is part of a container, and the bioactive material is positioned on an inner surface of the outer layer. In some embodiments, one or more additional layers can be provided between the bioactive layer and the outer layer and/or the bioactive layer and the inner layer. In some embodiments, the bioactive material is positioned on a surface of the inner layer. In some embodiments, the inner layer is part of a container, and the bioactive material is positioned on an outer surface of the inner layer.

[0053] In some embodiments, the microorganism can be cultured in a metabolically normal state and then induced into a metabolically quiescent state. In some embodiments, the batch is purified before and/or after induction into the metabolically quiescent state. In some embodiments, the microorganism is induced into the metabolically quiescent state through at least one of: nutrient deprivation, incubation at a temperature substantially different from the normal culturing temperature of the microorganism, incubation of the microbe under osmotic conditions substantially different from normal osmotic conditions, oxygen deprivation (for example, for aerobic microorganisms), contacting the microorganism with a food preservative, and/or genetically modifying the microorganism. In some embodiments, the nutrients deprived from the microorganism include one or more of carbohydrates, nitrogen, and essential amino acids. In some embodiments, the microorganism is cultivated in a hypertonic solution.

[0054] In some embodiments, the microorganism can be embedded in a matrix. In some embodiments, embedding the microorganism in the matrix includes combining the microorganism with a matrix material. In some embodiments, the microorganism is mixed with at least one ingredient that can be used to form the matrix. In some embodiments, the microorganism is added to a mixture that includes monomers and/or subunits for the creation of a matrix polymer. In some embodiments, embedding the microorganism in the matrix includes polymerizing the monomers and/or subunits such that the microorganism is trapped and/or associated with the matrix material after the polymerization. In some embodiments, embedding the microorganism in the matrix includes cross-linking the matrix material. In some embodiments, embedding the microorganism in the matrix includes polymerizing and cross-linking.

[0055] In some embodiments, the matrix material is applied to a layer of the packaging material. In some embodiments, the matrix is applied to a layer of the packaging material, and the layer is then incorporated into a container. In some

embodiments, a layer of the packaging material is incorporated into a container and the matrix is applied to the layer. In some embodiments, the matrix material is applied to an inner surface of the outer layer. In some embodiments, the matrix material is applied to an outer surface of the inner layer. In some embodiments, two layers of the packaging material are incorporated into a container, and the matrix is inserted between the layers, for example between the inner layer and the outer layer. In some embodiments, the matrix is sprayed onto one or both layers. In some embodiments, the matrix is spread onto the layer. In some embodiments, the matrix is poured onto a layer. In some embodiments, the matrix material is spread, sprayed, or poured onto a layer and then cross-linked, polymerized, or polymerized and cross-linked to increase its viscosity and/or trap and/or associate a microorganism with the matrix material.

[0056] In some embodiments, the microorganism is embedded in the matrix before the matrix is applied to the layer, for example by mixing the microorganism with matrix ingredients. In some embodiments, the microorganism is added to the matrix after the matrix is applied to the layer, for example by spreading the microorganism, or applying the microorganism via an aerosolized spray. In some embodiments, the microorganism is applied to the matrix material after the matrix material is crosslinked and/or polymerized.

[0057] In some embodiments, the matrix can be used as a skeleton for the packaging material and the outer layer can be sprayed onto the outside of the material, the microorganism can be added to the matrix, and then the inner layer can be sprayed inside the packaging material. In some embodiments, there need be no inner layer, if, for example, the microorganisms are harmless to the material to be stored and/or the microorganisms are fixed within a matrix or to the outer layer.

[0058] In some embodiments, the matrix includes the microorganisms, together with a matrix, and some basic nutrients and salts, in order to maintain viability, such as one or more of: peptides and casein peptones, vitamins (including B vitamin), trace elements (e.g. nitrogen, sulfur & magnesium), and/or minerals.

[0059] In some embodiments, the matrix can be made from a variety of materials, such as cross-linked starches, other carbohydrates, polynucleotides, proteins, or synthetic polymers. In some embodiments, the matrix and microorganisms are placed under high pressure, for example about 120 kilopascals, 150, 170, 190, 200, 210, 230, 250, 300, 400, or 500 kilopascals to facilitate spraying to form the matrix. In some cases,

this is sprayed to the inner barrier, and then applied (e.g. as an insert) to the outer barrier. In some cases, the matrix is cross-linked after application, such as by adding a cross-linking agent which specifically bonds the matrix polymers together, or specifically polymerizes the matrix material. In some cases, this is accomplished by heating and/or drying the matrix material, although the viability of the microorganisms needs to be taken into account with these methods.

[0060] In some embodiments, the microorganism is associated directly to at least one of the inner layer or the outer layer. In some embodiments, this can be achieved by hydrophobic forces. In some embodiments, this can be achieved by cross-linking or other covalent bonds.

[0061] In some embodiments, the packaging materials provided herein can involve components that are recyclable and/or biodegradable.

EXAMPLES

EXAMPLE 1

INCREASED PRESERVATION OF FOOD

[0062] A food packaging material is provided. The food packaging material includes a glass outer layer, a crosslinked polymer based matrix coating the inside of the outer layer, and an oxygen permeable polymer coating the top of the matrix. Within the matrix is a colony of *Lactobacillus delbrueckii subsp. Bulgaricus*, and *Bacillus subtilis* as well as a food source for the colony. A piece of meat is placed within the food packaging material. Any oxygen present is converted to carbon dioxide by the colony, thereby reducing the presence of oxygen and reducing the activity of other microorganisms that depend upon oxygen for replication and/or survival.

EXAMPLE 2

LONG TERM STORAGE OF PHARMACEUTICALS

[0063] A plastic packaging material is provided. The packaging material includes a rigid plastic outer layer, a starch based matrix coating the inside of the packaging material, and an oxygen permeable polymer coating on top of the matrix. Within the matrix is a colony of *Neurospora* as well as a sugar based food source for the colony. A collection of pills are placed within the plastic packaging material. Any

oxygen present is converted by the colony to carbon dioxide, thereby reducing the presence of oxygen and reducing the oxidation of the pharmaceuticals.

EXAMPLE 3

METHOD OF FLAVOR MODIFICATION

[0064] A food packaging material is provided. The food packaging material includes a glass outer layer, a crosslinked polymer based matrix coating the inside of the packaging material, and an oxygen and lactic acid permeable polymer coating on top of the matrix. Within the matrix is a colony of *Streptococcus lactis*. A quantity of milk is placed within the food packaging material. Any oxygen present is converted by the colony to carbon dioxide, thereby reducing the presence of oxygen and reducing oxidation of the milk. At the same time, the *Streptococcus lactis* can convert the lactose in the milk to lactic acid, thereby creating butter milk.

[0065] The present disclosure is not to be limited in terms of the particular embodiments described in this application, which are intended as illustrations of various aspects. Many modifications and variations can be made without departing from its spirit and scope, as will be apparent to those skilled in the art. Functionally equivalent methods and apparatuses within the scope of the disclosure, in addition to those enumerated herein, will be apparent to those skilled in the art from the foregoing descriptions. Such modifications and variations are intended to fall within the scope of the appended claims. The present disclosure is to be limited only by the terms of the appended claims, along with the full scope of equivalents to which such claims are entitled. It is to be understood that this disclosure is not limited to particular methods, reagents, compounds, compositions or biological systems, which can, of course, vary. It is also to be understood that the terminology used herein is for the purpose of describing particular embodiments only, and is not intended to be limiting.

[0066] With respect to the use of substantially any plural and/or singular terms herein, those having skill in the art can translate from the plural to the singular and/or from the singular to the plural as is appropriate to the context and/or application. The various singular/plural permutations may be expressly set forth herein for sake of clarity.

[0067] It will be understood by those within the art that, in general, terms used herein, and especially in the appended claims (*e.g.*, bodies of the appended claims) are

generally intended as “open” terms (*e.g.*, the term “including” should be interpreted as “including but not limited to,” the term “having” should be interpreted as “having at least,” the term “includes” should be interpreted as “includes but is not limited to,” etc.). It will be further understood by those within the art that if a specific number of an introduced claim recitation is intended, such an intent will be explicitly recited in the claim, and in the absence of such recitation no such intent is present. For example, as an aid to understanding, the following appended claims may contain usage of the introductory phrases “at least one” and “one or more” to introduce claim recitations. However, the use of such phrases should not be construed to imply that the introduction of a claim recitation by the indefinite articles “a” or “an” limits any particular claim containing such introduced claim recitation to embodiments containing only one such recitation, even when the same claim includes the introductory phrases “one or more” or “at least one” and indefinite articles such as “a” or “an” (*e.g.*, “a” and/or “an” should be interpreted to mean “at least one” or “one or more”); the same holds true for the use of definite articles used to introduce claim recitations. In addition, even if a specific number of an introduced claim recitation is explicitly recited, those skilled in the art will recognize that such recitation should be interpreted to mean at least the recited number (*e.g.*, the bare recitation of “two recitations,” without other modifiers, means at least two recitations, or two or more recitations). Furthermore, in those instances where a convention analogous to “at least one of A, B, and C, etc.” is used, in general such a construction is intended in the sense one having skill in the art would understand the convention (*e.g.*, “a system having at least one of A, B, and C” would include but not be limited to systems that have A alone, B alone, C alone, A and B together, A and C together, B and C together, and/or A, B, and C together, etc.). In those instances where a convention analogous to “at least one of A, B, or C, etc.” is used, in general such a construction is intended in the sense one having skill in the art would understand the convention (*e.g.*, “a system having at least one of A, B, or C” would include but not be limited to systems that have A alone, B alone, C alone, A and B together, A and C together, B and C together, and/or A, B, and C together, etc.). It will be further understood by those within the art that virtually any disjunctive word and/or phrase presenting two or more alternative terms, whether in the description, claims, or drawings, should be understood to contemplate the possibilities of including one of the terms, either

of the terms, or both terms. For example, the phrase “A or B” will be understood to include the possibilities of “A” or “B” or “A and B.”

[0068] In addition, where features or aspects of the disclosure are described in terms of Markush groups, those skilled in the art will recognize that the disclosure is also thereby described in terms of any individual member or subgroup of members of the Markush group.

[0069] As will be understood by one skilled in the art, for any and all purposes, such as in terms of providing a written description, all ranges disclosed herein also encompass any and all possible subranges and combinations of subranges thereof. Any listed range can be easily recognized as sufficiently describing and enabling the same range being broken down into at least equal halves, thirds, quarters, fifths, tenths, etc. As a non-limiting example, each range discussed herein can be readily broken down into a lower third, middle third and upper third, etc. As will also be understood by one skilled in the art all language such as “up to,” “at least,” and the like include the number recited and refer to ranges which can be subsequently broken down into subranges as discussed above. Finally, as will be understood by one skilled in the art, a range includes each individual member. Thus, for example, a group having 1-3 cells refers to groups having 1, 2, or 3 cells. Similarly, a group having 1-5 cells refers to groups having 1, 2, 3, 4, or 5 cells, and so forth.

[0070] From the foregoing, it will be appreciated that various embodiments of the present disclosure have been described herein for purposes of illustration, and that various modifications may be made without departing from the scope and spirit of the present disclosure. Accordingly, the various embodiments disclosed herein are not intended to be limiting, with the true scope and spirit being indicated by the following claims.

WHAT IS CLAIMED IS:

1. A packaging material comprising:
an outer layer, wherein the outer layer is effectively impermeable to oxygen;
an inner layer, wherein the inner layer is effectively permeable to oxygen;
and
a bioactive material, wherein in the bioactive material is located between the inner layer and the outer layer, and wherein the bioactive layer comprises at least one microorganism.
2. The packaging material of claim 1, wherein the at least one microorganism comprises a living microorganism.
3. The packaging material of claim 1, wherein the at least one microorganism comprises a bacterium or a yeast.
4. The packaging material of claim 1, wherein the at least one microorganism is aerobic.
5. The packaging material of claim 1, wherein the at least one microorganism is substantially in a metabolically quiescent state.
6. The packaging material of claim 1, wherein the at least one microorganism can survive a temperature of 120° Centigrade.
7. The packaging material of claim 1, wherein the at least one microorganism can survive a pressure of 200 kilopascals.
8. The packaging material of claim 1 further comprising a matrix positioned between the outer layer and the inner layer, wherein the at least one microorganism is associated with the matrix.
9. The packaging material of claim 8, wherein the matrix comprises at least one of a starch, a carbohydrate, a polynucleotide, a protein, or a synthetic polymer.
10. The packaging material of claim 8, wherein the matrix comprises at least one of a peptide, a casein peptone, a vitamin, or a trace element.
11. The packaging material of claim 1, wherein the inner layer comprises at least one of a polymer film or an insert.
12. The packaging material of claim 1, wherein the outer layer, inner layer, or both the outer layer and the inner layer provide a rigid wall of the packaging material.

13. The packaging material of claim 1, wherein the packaging material is in the shape of a storage container.

14. The packaging material of claim 13, wherein the storage container is a food storage container.

15. The packaging material of claim 14, wherein the food storage container comprises a first opening.

16. The packaging material of Claim 15, wherein the first opening is configured to receive a lid so as to provide an effectively airtight seal for any material within the food storage container.

17. The packaging material of Claim 16, wherein the packaging material defines a volume of four liters or less, when the first opening is sealed by the lid.

18. The packaging material of Claim 16, wherein the packaging material defines a volume of 1 liter or less, when the first opening is sealed by the lid.

19. The packaging material of Claim 13, wherein the storage container is a bag.

20. The packaging material of Claim 19, wherein the bag is self sealing.

21. A method of containing an item, the method comprising:

providing a packaging material, the packaging material comprising:

an outer layer, wherein the outer layer is effectively impermeable to oxygen;

an inner layer, wherein the inner layer is permeable to oxygen; and

a bioactive material, wherein in the bioactive material is located between the inner layer and the outer layer, and wherein the bioactive layer comprises at least one microorganism; and

exposing an item to the packaging material, wherein a surface of the inner layer faces a surface of the item, thereby containing the item.

22. The method of claim 21, wherein the inner layer is proximal to the item and the outer layer is distal to the item.

23. The method of claim 21, wherein the item comprises a perishable food product.

24. The method of claim 21, wherein the packaging material forms at least a part of a container.

25. The method of claim 24, wherein exposing the item to the packaging material comprises placing the item within the container.

26. The method of claim 25, further comprising sealing the container with the item inside of the container, to provide a sealed container.

27. The method of claim 26, wherein a substantially air-tight seal is provided in order to seal the container.

28. The method of claim 26, wherein when the item is within the sealed container, there is a headspace volume.

29. The method of claim 28, wherein the headspace volume comprises a first percent of oxygen immediately after the container is sealed.

30. The method of claim 29, wherein the headspace volume comprises a second percent of oxygen 2 hours after the container is sealed, wherein the second percent is less than the first percent.

31. The method of claim 28, wherein the headspace volume is in fluid communication with the bioactive material.

32. The method of claim 31, wherein an amount of oxygen within the headspace volume passes through the inner layer to the bioactive layer, and wherein the amount of oxygen is exchanged with an amount of carbon dioxide by the at least one microorganism.

33. A method of making a packaging material, the method comprising:
providing an outer layer, wherein the outer layer is substantially impermeable to oxygen;
providing a bioactive material; and
providing an inner layer, wherein the inner layer is permeable to oxygen, and wherein the bioactive material is positioned between the outer layer and the inner layer, thereby making a packaging material.

34. The method of claim 33, wherein providing a bioactive material comprises:

providing at least one microorganism;
inducing the at least one microorganism into a metabolically quiescent state; and
embedding the at least one microorganism in a matrix, thereby providing the bioactive material.

35. The method of claim 34, wherein embedding the at least one microorganism comprises combining the at least one microorganism and a matrix material and cross-linking, polymerizing, or both cross-linking and polymerizing the matrix material.

36. The method of claim 35, wherein the matrix is applied to an inner surface of the outer layer.

37. The method of claim 35, wherein the matrix is applied to an outer surface of the inner layer.

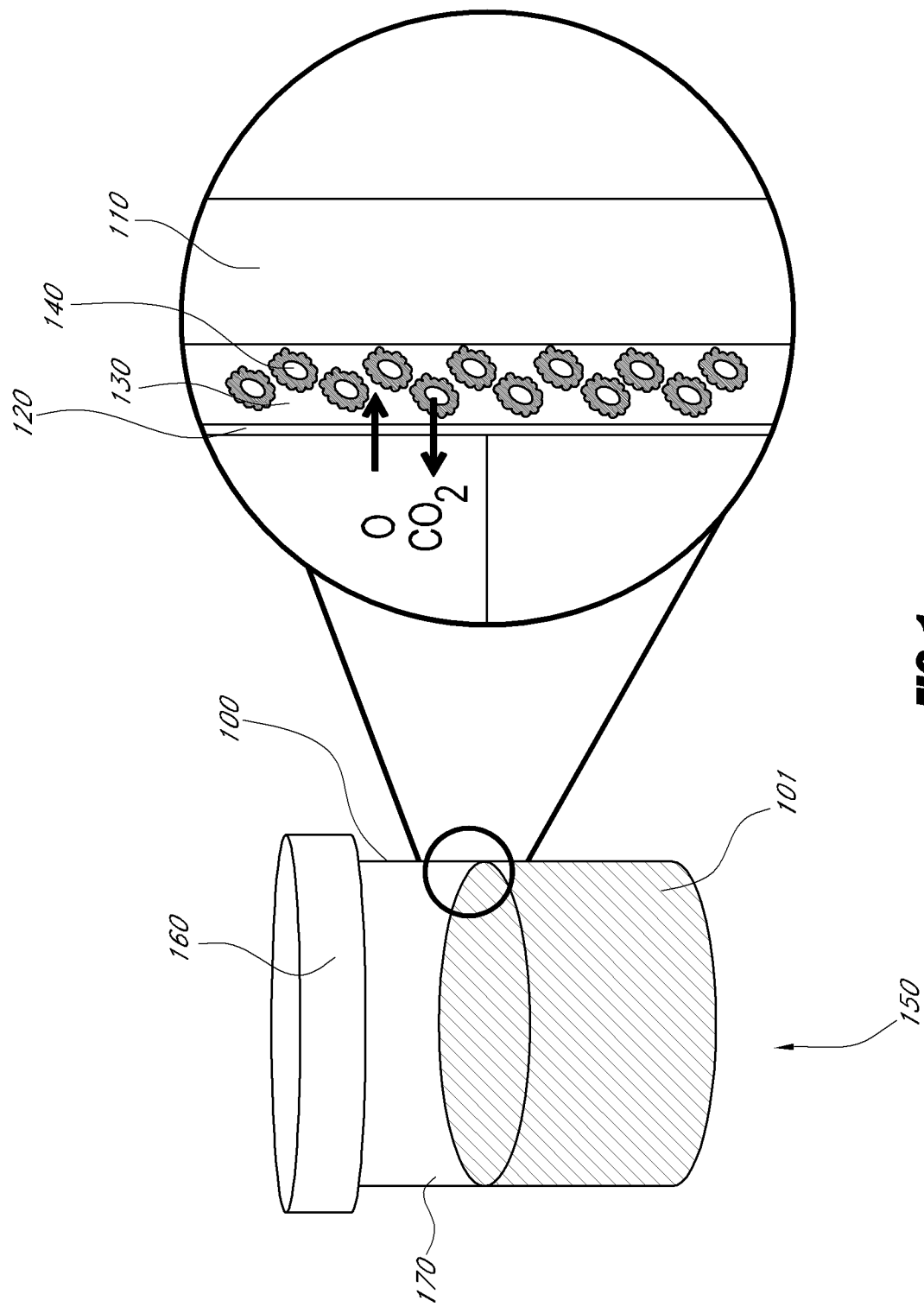


FIG. 1

FIGURE 2

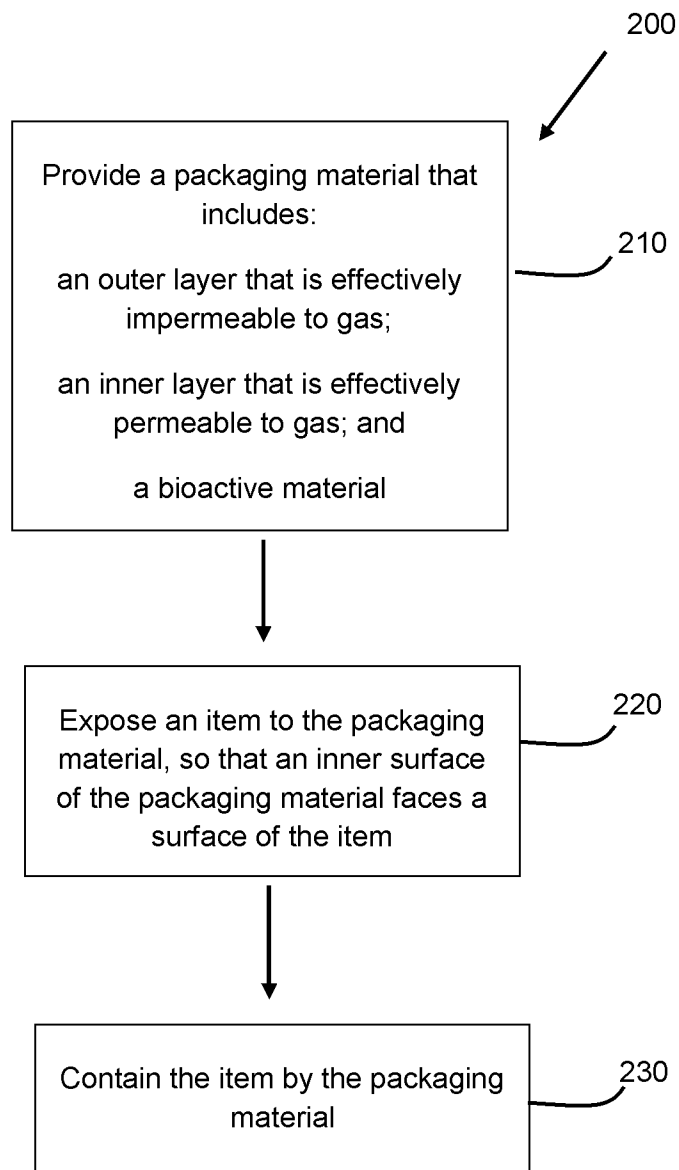
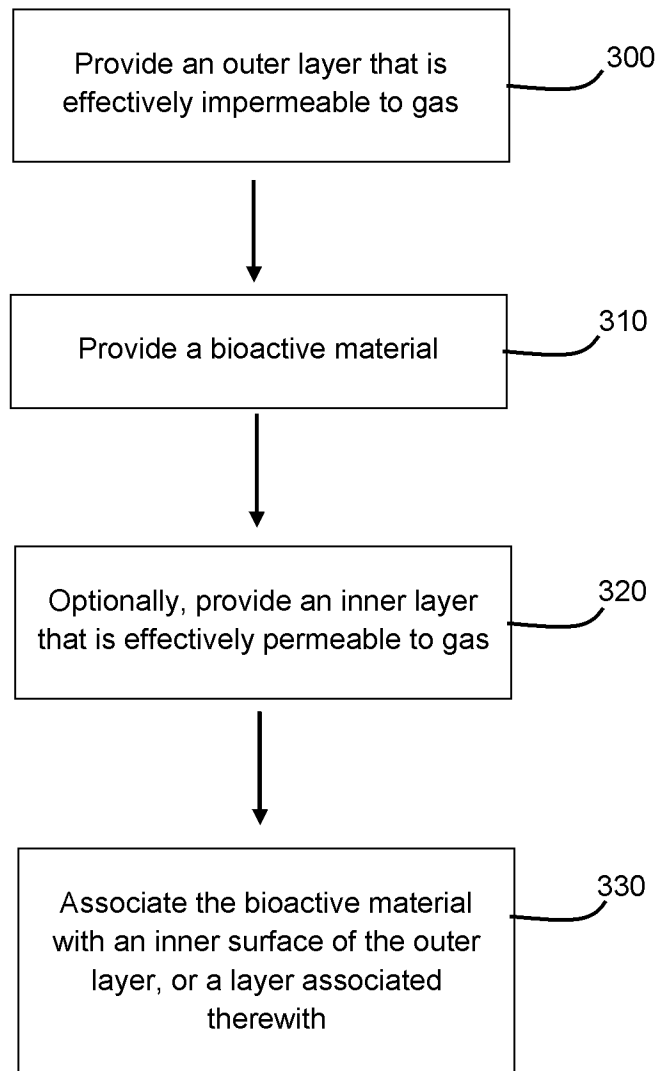


FIGURE 3



INTERNATIONAL SEARCH REPORT

International application No.

PCT/US2012/045533

A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - B32B 27/32 (2012.01)

USPC - 428/34.8

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)

IPC(8) - B32B 27/06, 27/32, 29/00, 37/16 (2012.01)

USPC - 428/34.3, 34.6, 34.8, 35.6, 35.7, 35.9

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)

Orbit.com, Google Patents, Google

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2007/0212461 A1 (LILLEVANG et al) 13 September 2007 (13.09.2007) entire document	1-37
A	MOLINA-GUTIERREZ et al. In situ determination of the intracellular pH of Lactococcus lactis and Lactobacillus plantarum during pressure treatment. September 2002. entire document	7
A	US 2008/0241521 A1 (SOLOVYOV et al) 02 October 2008 (02.10.2008) entire document	1-37
A	US 6,037,022 A (ADUR et al) 14 March 2007 (14.03.2007) entire document	1-37

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


* Special categories of cited documents:

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

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

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

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

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

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