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## RETROREFLECTIVE ARTICLE

### Abstract


A retroreflective article includes a mesh layer including a plurality of interconnected portions defining a plurality of enclosed openings therebetween, a bond layer, and a plurality of sets of optical elements. The bond layer includes a plurality of bond portions at least partially spaced apart from each other by the mesh layer. Each bond portion is at least partially disposed within a corresponding enclosed opening and fixedly bonded to one or more adjacent interconnected portions of the mesh layer. The plurality of sets of optical elements corresponds to the plurality of bond portions of the bond layer. Each of the sets of optical elements includes a plurality of optical elements partially embedded within a corresponding bond portion from the plurality of bond portions of the bond layer. The sets of optical elements are spaced apart from each other by the one or more interconnected portions of the mesh layer.



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## Background/Summary

TECHNICAL FIELD
[0001] The present disclosure relates to a retroreflective article and a method of manufacturing the retroreflective article.
BACKGROUND
[0002] Retroreflective articles are used in a variety of applications. For example, the retroreflective articles are often used as high-visibility trims on garments and footwear to increase a visibility of a user wearing the garments and the footwear. The retroreflective articles are often added to garments that are worn by firefighters, rescue personnel, road workers, and the like.
SUMMARY
[0003] In a first aspect, the present disclosure provides a retroreflective article. The retroreflective article includes a mesh layer. The mesh layer includes a plurality of interconnected portions defining a plurality of enclosed openings therebetween, a first mesh major surface, and a second mesh major surface opposite to the first mesh major surface. The plurality of interconnected portions together form the first mesh major surface and the second mesh major surface. The retroreflective article further includes a bond layer including a plurality of bond portions at least partially spaced apart from each other by the mesh layer. Each of the plurality of bond portions is at least partially disposed within a corresponding enclosed opening from the plurality of enclosed openings and fixedly bonded to one or more adjacent interconnected portions from the plurality of interconnected portions of the mesh layer. The second mesh major surface is proximal to the bond layer. The retroreflective article further includes a plurality of sets of optical elements corresponding to the plurality of bond portions of the bond layer. Each of the sets of optical elements includes a plurality of optical elements partially embedded within a corresponding bond portion from the plurality of bond portions of the bond layer. The first mesh major surface is proximal to the sets of optical elements. The sets of optical elements are spaced apart from each other by the one or more interconnected portions of the mesh layer.
[0004] In a second aspect, the present disclosure provides a method of manufacturing a retroreflective article. The method includes providing a carrier layer. The method further includes disposing a mesh layer on the carrier layer. The mesh layer includes a plurality of interconnected portions defining a plurality of enclosed openings therebetween, a first mesh major surface, and a second mesh major surface opposite to the first mesh major surface. The plurality of interconnected portions together form the first mesh major surface and the second mesh major surface. The first mesh major surface is disposed on the carrier layer. The method further includes disposing a plurality of optical elements within the plurality of enclosed openings of the mesh layer. The method further includes providing a reflective layer adjacent to a surface of at least some of the plurality of optical elements. The method further includes providing a bond layer at least partially on the reflective layer within the plurality of enclosed openings of the mesh layer, such that the plurality of optical elements is partially embedded within the bond layer. The bond layer fixedly bonds to the plurality of interconnected portions of the mesh layer.

## Description

## BRIEF DESCRIPTION OF THE DRAWINGS

[0005] Exemplary embodiments disclosed herein may be more completely understood in consideration of the following detailed description in connection with the following figures. The figures are not necessarily drawn to scale. In particular, thicknesses of certain layers in proportion to certain other items are exaggerated for ease of illustration and clarity purposes. Like numbers used in the figures refer to like components. However, it will be understood that the use of a number to refer to a component in a given figure is not intended to limit the component in another figure labeled with the same number.

[0006] FIG. **1** is a schematic cross-sectional view of a retroreflective article according to an embodiment of the present disclosure;

[0007] FIG. **2** is a schematic perspective view of a mesh layer of the retroreflective article according to an embodiment of the present disclosure;

[0008] FIG. **3** is a schematic cross-sectional view of a retroreflective article according to another embodiment of the present disclosure;

[0009] FIG. **4** is a schematic front view of a garment including the retroreflective article according to an embodiment of the present disclosure;

[0010] FIG. **5** is a flowchart depicting various steps of a method of manufacturing a retroreflective article according to an embodiment of the present disclosure; and

[0011] FIGS. **6**A-**6**H are schematic views depicting various steps of the method of manufacturing the retroreflective according to an embodiment of the present disclosure.

## DETAILED DESCRIPTION

[0012] In the following description, reference is made to the accompanying figures that form a part thereof and in which various embodiments are shown by way of illustration. It is to be understood that other embodiments are contemplated and may be made without departing from the scope or spirit of the present disclosure. The following detailed description, therefore, is not to be taken in a limiting sense.

[0013] In the following disclosure, the following definitions are adopted.

[0014] As recited herein, all numbers should be considered modified by the term “about”. As used herein, “a,” “an,” “the,” “at least one,” and “one or more” are used interchangeably.

[0015] As used herein as a modifier to a property or attribute, the term “generally”, unless otherwise specifically defined, means that the property or attribute would be readily recognizable by a person of ordinary skill but without requiring absolute precision or a perfect match (e.g., within +/−20% for quantifiable properties).

[0016] The term “substantially”, unless otherwise specifically defined, means to a high degree of approximation (e.g., within +/−10% for quantifiable properties) but again without requiring absolute precision or a perfect match.

[0017] The term “about”, unless otherwise specifically defined, means to a high degree of approximation (e.g., within +/−5% for quantifiable properties) but again without requiring absolute precision or a perfect match.

[0018] Terms such as same, equal, uniform, constant, strictly, and the like, are understood to be within the usual tolerances or measuring error applicable to the particular circumstance rather than requiring absolute precision or a perfect match.

[0019] As used herein, the terms “first” and “second” are used as identifiers. Therefore, such terms should not be construed as limiting of this disclosure. The terms “first” and “second” when used in conjunction with a feature or an element can be interchanged throughout the embodiments of this disclosure.

[0020] As used herein, when a first material is termed as “similar” to a second material, at least 90 weight % of the first and second materials are identical and any variation between the first and second materials comprises less than about 10 weight % of each of the first and second materials.

[0021] As used herein, “at least one of A and B” should be understood to mean “only A, only B, or both A and B”.

[0022] Unless specified or limited otherwise, the terms “attached,” “connected,” and variations thereof, are used broadly and encompass both direct and indirect attachments, connections, and couplings.

[0023] As used herein, the term “adjacent” refers to elements that are in proximity to each other, usually in contact with each other, but may have intervening elements between them.

[0024] As used herein, the term “configured to” and like is at least as restrictive as the term “adapted to” and requires actual design intention to perform the specified function rather than mere physical capability of performing such a function.

[0025] As used herein, the term “at least partially” refers to any percentage greater than 1%. In other words, the term “at least partially” refers to any amount of a whole. For example, “at least partially” may refer to a small portion, half, or a selected portion of a whole. In some examples, “at least partially” may refer to a whole amount. The term “partially” refers to any percentage less than 100%.

[0026] As used herein, the term “spaced apart” refers to elements that are disposed at a distance from one another. A plurality of elements spaced apart from each other means that adjacent elements from the plurality of elements are disposed at a distance from one another. A plurality of elements at least partially spaced apart from each other means that at least portions of adjacent elements from the plurality of elements are disposed at a distance from one another.

[0027] As used herein, the term “retroreflective” refers to the attribute of reflecting an obliquely incident light ray in a direction antiparallel to its incident direction, or nearly so, such that it returns to the light source or an immediate vicinity thereof.

[0028] As used herein, the term “fixedly bonded” refers to two or more elements being attached to each other so that they are not intended to be separated or disconnected during normal use.

[0029] As used herein, the term “mesh layer” refers to a layer of an apertured material. A mesh layer may include cords, wires, or threads woven into a network defining apertures or openings, or a sheet or a film having apertures or openings cut, punched, or otherwise formed therein.

[0030] As used herein, the term “percent open area” refers to a percentage of an area of the mesh layer that is taken up by an open area of the apertures or openings.

[0031] The term “microsphere” or “microspheres” refers to either a population of micron size particles, or an individual particle, depending upon the context in which the word is used, which has a high sphericity measurement. The sphericity measurement of a population of microspheres may be in the range of about 80% to about 100%, with 95% being typical. The microspheres are substantially spherical, although a microsphere population may include some individual particles that have a lower sphericity measurement.

[0032] As used herein, the term “median diameter” refers to a diameter distribution where 50% of the particles are smaller than a given value.

[0033] As used herein, the term “garment” refers to an item that, in normal use, is to be donned and worn by a user. The term “garment” excludes any item that is itself to be attached to a garment.

[0034] As used herein, the term “external surface” of a garment refers to a surface, much or all of which is visible when the garment is worn.

[0035] As used herein, the term “elastomer” is defined as a polymer having an ability to be stretched to at least twice its original length and to retract to approximately its original length when released, (definition taken from “Hawley's Condensed Chemical Dictionary”, R. J. Lewis Sr. Ed., 12th Ed., Van Nostrand Reinhold Co., New York, N.Y. (1993)).

[0036] The present disclosure relates to a retroreflective article and a method of manufacturing the retroreflective article. The retroreflective article includes a mesh layer. The mesh layer includes a plurality of interconnected portions defining a plurality of enclosed openings therebetween, a first mesh major surface, and a second mesh major surface opposite to the first mesh major surface. The plurality of interconnected portions together form the first mesh major surface and the second mesh major surface. The retroreflective article further includes a bond layer including a plurality of bond portions at least partially spaced apart from each other by the mesh layer. Each of the plurality of bond portions is at least partially disposed within a corresponding enclosed opening from the plurality of enclosed openings and fixedly bonded to one or more adjacent interconnected portions from the plurality of interconnected portions of the mesh layer. The second mesh major surface is proximal to the bond layer. The retroreflective article further includes a plurality of sets of optical elements corresponding to the plurality of bond portions of the bond layer. Each of the sets of optical elements includes a plurality of optical elements partially embedded within a corresponding bond portion from the plurality of bond portions of the bond layer. The first mesh major surface is proximal to the sets of optical elements. The sets of optical elements are spaced apart from each other by the one or more interconnected portions of the mesh layer.

[0037] The mesh layer of the retroreflective article of the present disclosure is disposed between the plurality of bond portions and the plurality of sets of optical elements. As a result, the retroreflective article may be very thin (e.g., have a thickness of about 0.25 millimeters (mm), or about 0.20 mm, or about 0.15 mm, or about 0.10 mm, or about 0.05 mm). In some cases, the retroreflective article may be as thin as the mesh layer. Such low thickness may provide a good/soft hand feel and high drapability to the retroreflective article. Further, the mesh layer may form a portion of an external surface of a garment to which the retroreflective article is attached. Consequently, the mesh layer may provide physical support and excellent abrasion resistance to the retroreflective article.

[0038] In some examples, the mesh layer includes a mesh fabric. The mesh fabric may have hydrophobic (water repellent), lipophobic (oil repellent), or wicking properties. As a result, the mesh fabric may dry quickly. The mesh fabric may have a fluorescent color in order to increase visibility of the retroreflective article and a garment to which the retroreflective article may be attached. The mesh fabric may further impart various other advantageous properties to the retroreflective article.

[0039] Referring now to Figures, FIG. **1** illustrates a schematic cross-sectional view of a retroreflective article **100** according to an embodiment of the present disclosure.

[0040] The retroreflective article **100** defines mutually orthogonal x, y, and z-axes. The x-axis is defined along a length of the retroreflective article **100**, while the y-axis is defined along a breadth of the retroreflective article **100**. The z-axis is defined along a thickness of the retroreflective article **100**.

[0041] The retroreflective article **100** includes a mesh layer **110**. The mesh layer **110** is also shown in FIG. **2**. Referring to FIGS. **1** and **2**, the mesh layer **110** includes a plurality of interconnected portions **112** defining a plurality of enclosed openings **114** (best shown in FIG. **2**) therebetween. The mesh layer **110** may include any apertured structure, i.e., a structure including a plurality of apertures (i.e., the plurality of enclosed openings **114**).

[0042] In some cases, such apertured structure may inherently include the plurality of enclosed openings **114** from a process of manufacturing, and may not necessarily require any kind of post-processing to form the plurality of enclosed openings **114**. In some other cases, the plurality of enclosed openings **114** may be formed on a structure by way of a post-process, e.g., mechanical perforation (e.g., by die-cutting), water-jet cutting, laser-cutting, needle-punching, and so forth.

[0043] In such cases, a shape of the plurality of enclosed openings **114** may be established by a particular method and equipment used, e.g., round, oval, square, hexagonal, and so forth. In an example, the mesh layer **110** may include cords, wires, or threads woven into a network defining the plurality of enclosed openings **114**. In another example, the mesh layer **110** may include a sheet or a film having the plurality of enclosed openings **114** cut, punched, or otherwise formed therein. For example, the mesh layer **110** may include a perforated polymer film including, for example, polyester (e.g., polyethylene terephthalate), polyamide (e.g., hexamethylene adipamide, polycaprolactam), polypropylene, acrylic, cellulose acetate, polyvinylidene chloride-vinyl chloride copolymers, and/or vinyl chloride-acrylonitrile copolymers. Perforation may be provided by die punching, needle punching, knife cutting, laser perforating, and slitting as described in U.S. Pat. No. 9,168,636 (Wald et al.) and U.S. Pat. No. 9,138,031 (Wood et al.), for example, which are incorporated herein in their entirety by reference. Perforation may also be provided by applying a flame, a heat source, or pressurized fluid, as described in U.S. Patent Application No 2016/0009048 A1 (Slama et al.) and U.S. Pat. No. 7,037,100 (Strobel et al.), for example, which are incorporated herein in their entirety by reference.

[0044] As shown in FIG. **2**, in some embodiments, the plurality of interconnected portions **112** may include a set of first members **112**A oriented in a first direction. The plurality of interconnected portions **112** may further include a set of second members **112**B oriented in a second direction different from the first direction. The first and second members **112**A, **112**B may meet at junctions **113**. In the illustrated embodiment of FIG. **2**, each of the set of first members **112**A is oriented substantially along the y-axis. Further, each of the set of second members **112**B is oriented substantially along the x-axis. Consequently, each of the plurality of enclosed openings **114** is substantially rectangular in FIG. **2**. However, the plurality of interconnected portions **112** may include any number of members, in any suitable configuration, to define the plurality of enclosed openings **114** that are, for example, circular, lozenge (e.g., diamond shaped), pentagonal, hexagonal, etc. In other words, many variations of the mesh layer **110** are possible, which involve members, such as the first and second members **112**A, **112**B, that are oriented in more than two directions, members that meet at relatively complex junctions as compared to the junctions **113** of FIG. **2**, and so forth.

[0045] In some embodiments, the mesh layer **110** has a percent open area of at least 70%. In other words, in some embodiments, the plurality of enclosed openings **114** may occupy at least 70% of a total area of the mesh layer **110**. In one example, the plurality of enclosed openings **114** may occupy 75% of the total area of the mesh layer **110**, and the plurality of interconnected portions **112** may occupy 25% of the total area of the mesh layer **110**.

[0046] The mesh layer **110** further includes a first mesh major surface **110**A and a second mesh major surface **110**B opposite to the first mesh major surface **110**A. Specifically, the plurality of interconnected portions **112** together form the first mesh major surface **110**A and the second mesh major surface **110**B. In other words, the first mesh major surface **110**A and the second mesh major surface **110**B are collectively formed by the plurality of interconnected portions **112**.

[0047] The mesh layer **110** defines a thickness **110**T between the first mesh major surface **110**A and the second mesh major surface **110**B along the z-axis. In some embodiments, the mesh layer **110** has the thickness **110**T from 0.05 mm to about 2.5 mm. The thickness **110**T is shown to be uniform in FIGS. **1** and **2**, however, the thickness **110**T of the mesh layer **110** may vary along a length (along the x-axis) and/or a breadth (along the y-axis) of the mesh layer **110**. In some examples, the thickness **110**T of the mesh layer **110** may vary from about 0.05 mm to about 2.5 mm along the length and/or the breadth of the mesh layer **110**.

[0048] The mesh layer **110** may be naturally colored (e.g., in a color of a material from which the mesh layer **110** is made), or artificially colored. In some embodiments, the mesh layer **110** has a colorant. In other words, in some embodiments, the mesh layer **110** is colored (to a desired color) by the colorant. Preferably, the mesh layer **110** may have a fluorescent color (either naturally or artificially). As a result, the mesh layer **110** may exhibit a luminance (minimum luminance factor) that meets the criteria set out in ANSI 107-2015. The fluorescent color may improve a visibility of the retroreflective article **100** and a garment to which the retroreflective article **100** may be attached.

[0049] The mesh layer **110** may impart various advantageous properties to the retroreflective article **100**. For example, the mesh layer **110** may have hydrophobic (water repellent), lipophobic (oil repellent), or wicking properties. As a result, the mesh layer **110** may dry quickly. In another example, the mesh layer **110** may be flame retardant (to prevent or slow growth of fire). In another example, the mesh layer **110** may be elastic (e.g., made from LYCRA® and other elastomeric fibers). In another example, the mesh layer **110** may be abrasion and puncture resistant. In another example, the mesh layer **110** may be either electrostatically dissipative or conductive. In another example, the mesh layer **110** may be thermally conductive. In another example, the mesh layer **110** may be phosphorescent (photoluminescent). In some cases, the mesh layer **110** may also be magnetic.

[0050] In some embodiments, the mesh layer **110** includes a mesh fabric. For example, the plurality of interconnected portions **112** of the mesh layer **110** may include any suitable bondable yarns, such as spun yarns (e.g., spun yarns composed of cotton fibers and/or polyester fibers). The mesh fabric may include knit fabrics, open weave fabrics, woven meshes/screens (e.g., wire mesh or fiberglass mesh), unitary meshes (e.g., unitary continuous plastic screens), or perforated nonporous (e.g., sealed) fabrics. In some embodiments, the mesh fabric may include an integral loop substrate, especially in the case of knit fabrics.

[0051] The retroreflective article **100** further includes a bond layer **120**. The bond layer **120** includes a plurality of bond portions **122** at least partially spaced apart from each other by the mesh layer **110**. Further, each of the plurality of bond portions **122** is at least partially disposed within a corresponding enclosed opening **114** from the plurality of enclosed openings **114**. Specifically, at least a portion of adjacent bond portions **122** may be spaced apart from each other by a corresponding interconnected portion **112** from the plurality of interconnected portions **112** of the mesh layer **110**. As a result, at least one interconnected portion **112** from the plurality of interconnected portions **112** may be disposed between adjacent bond portions **122** from the plurality of bond portions **122**.

[0052] Each of the plurality of bond portions **122** is fixedly bonded to one or more adjacent interconnected portions **112** from the plurality of interconnected portions **112**. In other words, each of the plurality of bond portions **122** may not de-bond or disconnect from the one or more adjacent interconnected portions **112**. The plurality of bond portions **122** is not intended to be de-bonded or disconnected from the plurality of interconnected portions **112** during use of the retroreflective article **100**.

[0053] Each of the plurality of bond portions **122** is spaced apart from the first mesh major surface **110**A along the thickness **110**T of the mesh layer **110**. As illustrated in FIG. **1**, each of the plurality of bond portions **122** is disposed below the first mesh major surface **110**A. Further, the second mesh major surface **110**B is proximal to the bond layer **120**. In other words, the second mesh major surface **110**B is proximal to each of the plurality of bond portions **122** of the bond layer **120**.

[0054] In the illustrated embodiment of FIG. **1**, the bond layer **120** is disposed between the first mesh major surface **110**A and the second mesh major surface **110**B along the thickness **110**T of the mesh layer **110**. Specifically, each of the plurality of bond portions **122** of the bond layer **120** is disposed within the corresponding enclosed opening **114**, such that they are located between the first mesh major surface **110**A and the second mesh major surface **110**B along the thickness **110**T of the mesh layer **110**. As a result, each of the plurality of bond portions **122** is spaced apart from the first mesh major surface **110**A and the second mesh major surface **110**B along the thickness **110**T of the mesh layer **110**. This may facilitate reduction of the thickness of the retroreflective article **100**, thereby allowing the retroreflective article **100** to be very thin (e.g., about 0.25 mm, or about 0.20 mm, or about 0.15 mm, or about 0.10 mm, or about 0.05 mm). It will be appreciated that in actual industrial production of the retroreflective article **100**, small-scale statistical fluctuations may inevitably be present that may result in a small amount of the bond layer **120** to be present on the second mesh major surface **110**B. Such occasional occurrences are to be expected in any real-life production process; however, the bond layer **120** of the retroreflective article **100**, as described above, is distinguished from circumstances in which the bond layer **120** is purposefully arranged in a continuous manner (i.e., portions thereof are not spaced apart from each other by the mesh layer

**110**).

[0055] In some embodiments, the bond layer **120** may include more than 20 weight percent of a polymeric binder. In some embodiments, the bond layer **120** includes a colorant and the polymeric binder. Specifically, in some embodiments, the bond layer **120** may include a flexible polymeric binder material that is colored in some fashion. The bond layer **120** may further include additives, such as UV stabilizers, antioxidants, UV absorbers, property modifiers, performance enhancers, or combinations thereof.

[0056] The polymeric binder of the bond layer **120** may include, but is not limited to, an elastomer. Specifically, the polymeric binder may include a cross-linked or virtually cross-linked elastomer. A cross-linked elastomer means that polymeric chains of the elastomer are chemically cross-linked to form a three dimensional network which is stabilized against molecular flow. A virtually cross-linked elastomer means that the polymeric chain mobility of the elastomer is greatly reduced by chain entanglement and/or by hydrogen bonding, resulting in an increase in the cohesive or internal strength of the polymer. Examples of such polymer cross-linking include carbon-carbon bond formation such as: free radical bonding between vinyl groups between chains; agent or group coupling such as by vulcanization or reaction with a coupling agent, such as a diol in the case of isocyanate or epoxy functionalized polymers; a diisocyanate or an activated ester in the case of amine and alcohol functionalized polymers; and epoxides and diols in the case of carboxylic acid or anhydride functionalized polymers. Examples of such virtual cross-linking include amide hydrogen bonding as is found in polyamides or crystalline and amorphous region interactions as is found in block copolymers of styrene and acrylonitrile.

[0057] Examples of the polymers that may be employed in the polymeric binder include polyolefins, polyesters, polyurethanes, polyepoxides, polyacrylates, natural and synthetic rubbers, and combinations thereof. Examples of cross-linked polymers include the foregoing examples of polymers substituted with cross-linkable groups such as epoxide groups, olefinic groups, isocyanate groups, alcohol groups, amine groups, anhydride groups, or acrylate groups. Multifunctional monomers and oligomers which react with functional groups of the polymers may also be used as cross-linkers.

[0058] Specific examples of materials for the bond layer **120** are disclosed in U.S. Pat. Nos. 5,200,262 and 5,283,101, the disclosures of which are incorporated herein in their entirety. In the '262 patent, the materials for the bond layer **120** includes one or more flexible polymers having active hydrogen functionalities, such as crosslinked urethane-based polymers (for example, isocyanate cured polyesters or one of two component polyurethanes) and one or more isocyanate-functional silane coupling agents. In the '101 patent, the materials for the bond layer **120** includes an electron-beam cured polymer selected from the group consisting of chlorosulfonated polyethylenes, ethylene copolymers including at least about 70 weight percent polyethylene, and poly(ethylene-co-propylene-co diene) polymers.

[0059] The retroreflective article **100** further includes a plurality of sets **131** of optical elements **130** corresponding to the plurality of bond portions **122** of the bond layer **120**. Each of the sets **131** of optical elements **130** includes a plurality of optical elements **130** partially embedded within a corresponding bond portion **122** from the plurality of bond portions **122** of the bond layer **120**.

[0060] The sets **131** of optical elements **130** are spaced apart from each other by the one or more interconnected portions **112** of the mesh layer **110**. Therefore, each of the sets **131** of optical elements **130** is discrete and disposed between adjacent interconnected portions **112**. The sets **131** of optical elements **130** are disposed proximal to the first mesh major surface **110**A. In other words, the first mesh major surface **110**A is proximal to the sets **131** of optical elements **130**.

[0061] Such an arrangement of the retroreflective article **100** may thus be distinguished from, for example, an approach in which the mesh layer **110** is not disposed between the plurality of bond portions **122** and the sets **131** of optical elements **130**.

[0062] In the illustrated embodiment of FIG. **1**, the retroreflective article **100** further includes a reflective layer **140** disposed adjacent to a surface **132** of at least some of the plurality of optical elements **130** facing the bond layer **120**. The surface **132**, adjacent to which the reflective layer **140** is disposed, faces the bond layer **120**. Therefore, in some embodiments, the reflective layer **140** is at least partially disposed between the plurality of optical elements **130** and the bond layer **120**. In one example, the reflective layer **140** may be disposed adjacent to the surface **132** via vapor deposition. During vapor deposition, in some cases, the reflective layer **140** may be further disposed on the second mesh major surface **110**B of the mesh layer **110**. Alternatively, in some embodiments, reflective particles (such as pearlescent pigments) may be added to the bond layer **120**, such as what is described in U.S. Pat. No. 32,28,897 (Nellessen), which is incorporated herein in its entirety. In these embodiments, the reflective layer **140** is located within the bond layer **120**.

[0063] The plurality of optical elements **130** and the reflective layer **140** may collectively return a substantial quantity of incident light towards a light source. That is, light that passes into and through the plurality of optical elements **130** is reflected by the reflective layer **140** to again reenter the plurality of optical elements **130**, such that the light is steered to return toward the light source, in the general manner signified by the term “retroreflection”.

[0064] In some embodiments, each of the plurality of optical elements **130** includes a transparent microsphere. In some embodiments, each of the plurality of optical elements **130** may include glass. For example, each of the plurality of optical elements **130** may be a transparent microsphere made substantially of glass. In some embodiments, each of the plurality of optical elements **130** has a diameter **130**D. The diameters **130**D of the plurality of optical elements **130** have a median diameter (D**50**). In some embodiments, the median diameter of the plurality of optical elements is from about 0.015 mm to about 0.2 mm. In some embodiments, the median diameter is about 0.05 mm, about 0.06 mm, about 0.07 mm, about 0.08 mm, about 0.09 mm, about 0.1 mm, about 0.12 mm, about 0.14 mm, about 0.16 mm, or about 0.18 mm.

[0065] The thickness **110**T of the mesh layer **110** may be selected based on the median diameter of the plurality of optical elements **130** and vice-versa. For example, the median diameter of the plurality of optical elements **130** may be less than the thickness **110**T of the mesh layer **110**. In some embodiments, a minimum thickness (i.e., a minimum value of the thickness **110**T) of the mesh layer **110** is greater than the median diameter of the plurality of optical elements **130** by a factor of at least 2.

[0066] In some embodiments, the reflective layer **140** includes a metal mirror or a dielectric mirror. The metal mirror may include elemental metal in pure or alloy form, which is capable of reflecting light, preferably specularly reflecting light. The metal may be a continuous coating produced by vacuum-deposition, vapor coating chemical-deposition, or electroless plating. In some examples, the metal mirror may be printed or transferred, as disclosed in U.S. Patent Application Publication No. 20200264349 (Chen-Ho et al.), which is incorporated herein in its entirety by reference. The metal mirror of the reflective layer **140** may have a thickness (along the z-axis) ranging from about 10 nanometers (nm) to about 500 nm.

[0067] A variety of metals may be used to provide a specularly reflective metal mirror. These include aluminum, silver, chromium, nickel, magnesium, gold, tin, and the like, in elemental form. Aluminum and silver are preferred metals for use in the metal mirror as they tend to provide good retroreflective brightness. In the case of aluminum and silver, some of the metal may be in the form of the metal oxide and/or hydroxide.

[0068] The dielectric mirror may also be referred to as a dichroic mirrors, Bragg reflectors, 1-D photonic crystals, or visible light reflectors (VLRs, i.e., when tuned to partially transmit and partially reflect light in the visible spectrum (i.e., from 400 nm to 700 nm)), which are each generally understood to those of skill in the art to at least partially reflect light within a desired band of wavelengths by employing alternating high and low refractive index layers. The dielectric mirror may be at least partially reflective and at least partially transparent. The term dielectric is used to refer to non-metallic and non-electrically conducting materials.

[0069] Typically, the dielectric mirror has a multi-layer construction. For example, the dielectric mirror may include a plurality of layers deposited, e.g., by layer-by-layer self-assembly. The dielectric mirror can include alternating stacks of optical thin films with different refractive indexes (RIs)—e.g., a “high” RI and a “low” RI. The interfaces between stacks with different RIs produce phased reflections, selectively reinforcing certain wavelengths (constructive interference) and cancelling other wavelengths (destructive interference). By selecting certain variables such as stack thickness, refractive indices, and number of the stacks, the band(s) of reflected and/or transmitted wavelengths can be tuned and made as wide or as narrow as desired. The dielectric mirror of the reflective layer **140** may have a thickness (along the z-axis) ranging from about 10 nanometers nm to about 500 nm.
[0070] In the illustrated embodiment of FIG. **1**, the retroreflective article **100** further incudes an interlayer **145** at least partially disposed between the plurality of optical elements **130** and the reflective layer **140**. The interlayer **145** may have a thickness (along the z-axis) from about 5 nm to about 0.03 mm. In some examples, the interlayer **145** may have various thickness along the length and/or the breadth of the retroreflective article **100**, i.e., its thickness may be zero or may approach zero. In one example, the interlayer **145** may be disposed substantially on the surface **132** of the plurality of optical elements **130** and may not be disposed between adjacent optical elements **130** from the plurality of optical elements **130**. In some other examples, the thickness the interlayer **145** may be less adjacent to the surface **132** of the plurality of optical elements **130**, and the thickness the interlayer **145** may be greater between adjacent optical elements **130** from the plurality of optical elements **130**.
[0071] The interlayer **145** may include a polymeric material. The interlayer **145** may preferably include a polymer that is linked to a silane coupling agent. To provide good laundering durability, the polymer preferably is a crosslinked polymer. Examples of polymers that may be suitable for the interlayer **145** include those that contain units of urethane, ester, ether, urea, epoxy, carbonate, acrylate, acrylic, olefin, vinyl chloride, amide, alkyd, or combinations thereof.
[0072] The polymer that is used in interlayer **145** may have functional groups that allow the polymer to be linked to the silane coupling agent, or the reactants that form the polymer may possess such functionality. For example, in producing polyurethanes, the starting materials may possess hydrogen functionalities that are capable of reacting with an isocyanate-functional silane coupling agent; see for example, U.S. Pat. No. 5,200,262 to Li, incorporated herein by reference in its entirety. Preferred polymers are crosslinked poly(urethane-ureas) and crosslinked poly(acrylates).
[0073] Poly(urethane-ureas) may be formed by reacting a hydroxy-functional polyester resin with excess polyisocyanate. Alternatively, a polypropylene oxide diol may be reacted with a diisocyanate and then with a triamino-functionalized polypropylene oxide. Crosslinked poly(acrylates) may be formed by exposing acrylate oligomers to electron beam radiation; see for example, U.S. Pat. No. 5,283,101 to Li incorporated herein by reference in its entirety.
[0074] In some embodiments, the retroreflective article **100** further includes an adhesive layer **150** disposed on at least one of the second mesh major surface **110**B of the mesh layer **110** and the bond layer **120** opposite to the plurality of optical elements **130**. In the illustrated embodiment of FIG. **1**, the adhesive layer **150** is disposed on each of the second mesh major surface **110**B of the mesh layer **110** and the bond layer **120** opposite to the plurality of optical elements **130**. The adhesive layer **150** may be applied to the mesh layer **110** and/or the bond layer **120** by, for example, liquid-coating, spraying, extrusion, lamination, and the like.
[0075] The adhesive layer **150** includes an adhesive. In some embodiments, the adhesive is one of a pressure sensitive adhesive and a hot-melt adhesive. In some embodiments, the adhesive may include a pressure sensitive adhesive, a heat activated adhesive, a laminating adhesive, or a combination of different types of adhesives. A wide variety of pressure sensitive adhesives are suitable, including tackified natural rubbers, synthetic rubbers, tackified styrene block copolymers,

polyvinyl ethers, poly (meth)acrylates, polyurethanes, polyureas, poly-alpha-olefins, and silicones. The pressure sensitive adhesive may be covered with a release liner to protect the adhesive prior to adhesion to a substrate. Heat activated adhesives are similar to pressure sensitive adhesives, but require the application of heat to become tacky. One advantage of heat activated adhesives is that they typically do not require a release liner to protect the adhesive layer prior to adhesion to a substrate because they are not tacky at room temperature. Examples of laminating adhesives include hot-melt adhesives, adhesive dispersions and suspensions, and curing adhesives, such as cyanoacrylates.

[0076] However, in some other embodiments, the adhesive layer **150** may be omitted from the retroreflective article **100**. In such embodiments, the retroreflective article **100** may be attached to a garment, for example, by sewing or stitching, by ultrasonic bonding, by use of hook and loop fasteners, and the like. One example of hook and loop mechanism include loops disposed on the second mesh major surface **110**B of the mesh layer **110** and hooks disposed on a garment on which the retroreflective article **100** is to be attached.

[0077] The retroreflective article **100** may be very thin (e.g., have a thickness of about 0.25 mm, or about 0.20 mm, or about 0.15 mm, or about 0.10 mm, or about 0.05 mm). In some cases, the retroreflective article **100** may be as thin as the mesh layer **110** (having the thickness **110**T). Such low thickness may provide a good/soft hand feel and high drapability to the retroreflective article **100**. Further, the mesh layer **110** may form a portion of an external surface of a garment to which the retroreflective article **100** is attached. Consequently, the mesh layer **110** may provide physical support and excellent abrasion resistance to the retroreflective article **100**.

[0078] FIG. **3** illustrates a schematic cross-sectional view of a retroreflective article **200** according to another embodiment of the present disclosure. The retroreflective article **200** is similar to the retroreflective article **100** of FIG. **1**, with like elements designated by like reference characters. However, the retroreflective article **200** has a different configuration of the bond layer **120**. Specifically, in the illustrated embodiment of FIG. **3**, each of the plurality of bond portions **122** extends below the second mesh major surface **110**B of the mesh layer **110** along the thickness **110**T of the mesh layer **110**. Further, in the illustrated embodiment of FIG. **3**, the adhesive layer **150** is disposed on the bond layer **120** opposite to the plurality of optical elements **130**.

[0079] FIG. **4** illustrates a schematic front view of a garment **300**. The garment **300** is illustrated in the form of a vest. However, the garment **300** may take form of, e.g., a jacket, a shirt (long-sleeve or short-sleeve), a pair of trousers, a pair of shoes, a coverall, and the like.

[0080] The garment **300** includes a body **310**. The body **310** may be made of a fabric (e.g., a breathable fabric), a leather material (e.g., for shoes), and so forth. The body **310** defines an external surface **311**, much or all of which is visible when the garment **300** is worn, and an internal surface **312**, much or all of which is not visible when the garment **300** is worn.

[0081] The garment **300** further includes the retroreflective article **100** or the retroreflective article **200** (shown in FIG. **3**). For explanatory purposes, the garment **300** will be described with reference to the retroreflective article **100**, however, the same concepts may be applied with the retroreflective article **200**.

[0082] The retroreflective article **100** may be attached to the body **310**, such that the first mesh major surface **110**A of the mesh layer **110** forms at least a portion of the external surface **311** of the garment **300**. The retroreflective article **100** may be attached to the body **310** by any suitable means. For example, the retroreflective article **100** may be attached to the body **310** by stitches, staples, adhesive, thermal or ultrasonic bonding, or by any other suitable means. In some embodiments, the adhesive layer **150** (shown in FIG. **1**) may bond the retroreflective article **100** to the body **310**, such that the first mesh major surface **110**A of the mesh layer **110** forms at least a portion of the external surface **311** of the garment **300**. In some cases, the second mesh major surface **110**B may enhance a surface bonding strength between the retroreflective article **100** and the garment **300** (e.g., via a loop on the second mesh major surface **110**B).

[0083] FIG. **5** illustrates a flowchart depicting various steps of a method **400** of manufacturing a retroreflective article. The method **400** may be used to manufacture the retroreflective article **100** of FIG. **1**. The method **400** may further be used to manufacture the retroreflective article **200** of FIG. **3**. Various steps of the method **400** are also illustrated in FIGS. **6**A-**6**H. The method **400** will be described with reference to FIGS. **1**, **5**, and **6**A-**6**H.
[0084] At step **402**, the method **400** includes providing a carrier layer. For example, the method **400** may include providing a carrier layer **160** (shown in FIG. **6**A).
[0085] In some embodiments, the carrier layer includes a liner and a carrier bonding layer. As shown in FIG. **6**A, in some embodiments, the carrier layer **160** includes a liner **161** and a carrier bonding layer **162**. The carrier bonding layer **162** may be disposed on the liner **161**. The carrier bonding layer **162** may be configured to temporarily bond with the mesh layer **110**. In some embodiments, the carrier bonding layer **162** may include a polymer (e.g., polyethylene). Further, the liner **161** may include any suitable material (e.g., a paper material) on which the carrier bonding layer **162** may be disposed.
[0086] At step **404**, the method **400** further includes disposing a mesh layer on the carrier layer. The mesh layer includes a plurality of interconnected portions defining a plurality of enclosed openings therebetween, a first mesh major surface, and a second mesh major surface opposite to the first mesh major surface. The plurality of interconnected portions together form the first mesh major surface and the second mesh major surface. The first mesh major surface is disposed on the carrier layer. For example, the mesh layer **110** may include the plurality of interconnected portions **112** defining the plurality of enclosed openings **114** therebetween. The mesh layer **110** may include the first mesh major surface **110**A and the second mesh major surface **110**B opposite to the first mesh major surface **110**A. The plurality of interconnected portions **112** may together form the first mesh major surface **110**A and the second mesh major surface **110**B. As shown in FIG. **6**B, the method **400** may include disposing the mesh layer **110** on the carrier layer **160**. Specifically, the method **400** may include disposing the first mesh major surface **110**A of the mesh layer **110** on the carrier layer **160**.
[0087] In some embodiments, disposing the mesh layer on the carrier layer further includes removably bonding the carrier layer to the mesh layer. For example, disposing the mesh layer **110** on the carrier layer **160** may include removably bonding the carrier layer **160** to the mesh layer **110**. Specifically, the carrier bonding layer **162** may removably bond to the mesh layer **110** and prevent unwanted delamination of the mesh layer **110** from the carrier layer **160** during manufacture of the retroreflective article. The mesh layer **110** may removably bond to the carrier bonding layer **162** by heat lamination.
[0088] At step **406**, the method **400** further includes disposing a plurality of optical elements within the plurality of enclosed openings of the mesh layer. For example, as shown in FIG. **6**C, the method **400** may include disposing the plurality of optical elements **130** within the plurality of enclosed openings **114** of the mesh layer **110**.
[0089] In some embodiments, disposing the plurality of optical elements within the plurality of enclosed openings further includes disposing the plurality of optical elements on the carrier layer. For example, disposing the plurality of optical elements **130** within the plurality of enclosed openings **114** may include disposing the plurality of optical elements **130** on the carrier layer **160**. The carrier bonding layer **162** of the carrier layer **160** may removably bond to the plurality of optical elements **130** and prevent unwanted delamination of the plurality of optical elements **130** from the carrier layer **160** during manufacture of the retroreflective article. The plurality of optical elements **130** may removably bond to the carrier bonding layer **162** by heat. Advantageously, the mesh layer **110** may protect the plurality of optical elements **130** during manufacturing.
[0090] Specifically, the mesh layer **110** may prevent delamination and loss of some of the plurality of optical elements **130** due to abrasion/static produced by winding and unwinding during manufacturing.

[0091] At step **408**, the method **400** further includes providing a bond layer adjacent to the plurality of optical elements within the plurality of enclosed openings of the mesh layer opposite to the carrier layer, such that the plurality of optical elements is partially embedded within the bond layer. The bond layer fixedly bonds to the plurality of interconnected portions of the mesh layer.

[0092] For example, as shown in FIG. **6**F, the method **400** may include providing the bond layer **120** at least partially on the reflective layer **140** within the plurality of enclosed openings **114** of the mesh layer **110**, such that the plurality of optical elements **130** is partially embedded within the bond layer **120**. The bond layer **120** may fixedly bond to the plurality of interconnected portions **112** of the mesh layer **110**. The bond layer **120** may thus be at least partially segmented and form the plurality of bond portions **122** within corresponding plurality of enclosed openings **114** of the mesh layer **110**. As shown in FIG. **6**F, the bond layer **120** may be provided on the reflective layer **140** opposite to the carrier layer **160**. A thickness of the bond layer **120** may reduce after the bond layer **120** dries.

[0093] As shown in FIG. **3**, in some embodiments, the plurality of bond portions **122** of the bond layer **120** may be at least partially spaced apart by the mesh layer **110**. This may be achieved by a normal coating/drying process to form the bond layer **120**. As shown in FIG. **1**, in some embodiments, the plurality of bond portions **122** of the bond layer **120** may be completely spaced apart from each other. The plurality of bond portions **122** may be completely spaced apart from each other, for example, when the mesh layer **110** has hydrophobicity to repel a solution of the bond layer **120** during coating or drying process. Alternatively, the plurality of bond portions **122** may be completely spaced apart from each other, for example, by registered printing, where a solution of the bond layer **120** is only delivered into the plurality of enclosed openings **114** of the mesh layer **110**.

[0094] In some embodiments, the method **400** further includes providing a reflective layer adjacent to a surface of at least some of the plurality of optical elements prior to providing the bond layer, such that the reflective layer is at least partially disposed between the bond layer and the plurality of optical elements. For example, as shown in FIG. **6**E, the method **400** may include providing the reflective layer **140** adjacent to the surface of **132** of at least some of the plurality of optical elements **130** prior to providing the bond layer **120**, such that the reflective layer **140** is at least partially disposed between the bond layer **120** and the plurality of optical elements **130**. The reflective layer **140** may be provided, for example, via vapor deposition. In some cases, the reflective layer **140** may be further disposed on the second mesh major surface **110**B of the mesh layer **110**.

[0095] In some embodiments, the method **400** further includes providing an interlayer on at least some of the plurality of optical elements prior to providing the reflective layer. For example, as shown in FIG. **6**D, the method **400** may include providing the interlayer **145** on at least some of the plurality of optical elements **130** prior to providing the reflective layer **140**.

[0096] In some embodiments, the method **400** further includes providing an adhesive layer on at least one of the second mesh major surface of the mesh layer and the bond layer opposite to the plurality of optical elements. For example, as shown in FIG. **6**G, the method **400** may further include providing the adhesive layer **150** on at least one of the second mesh major surface **110**B of the mesh layer **110** and the bond layer **120** opposite to the plurality of optical elements **130**. Specifically, as shown in FIG. **6**G, in some cases, the method **400** may further include providing the adhesive layer **150** on each of the second mesh major surface **110**B of the mesh layer **110** and the bond layer **120** opposite to the plurality of optical elements **130**.

[0097] In some embodiments, the method **400** further includes removing the carrier layer from the mesh layer and the plurality of optical elements **130**. For example, as shown in FIG. **6**H, the method **400** may include removing the carrier layer **160** from the mesh layer **110** and the plurality of optical elements **130**. Since the bond layer **120** is fixedly bonded to the one or more adjacent interconnected portions **112** from the plurality of interconnected portions **112** of the mesh layer

**110**, a bond strength between the bond layer **120** and the one or more interconnected portions **112** of the mesh layer **110** is greater than a bond strength between the mesh layer **110** and the carrier layer **160**. Further, a bond strength between the bond layer **120** and the plurality of optical elements **130** is greater than a bond strength between the plurality of optical elements **130** and the carrier layer **160**. After removal of the carrier layer **160**, the final product (e.g., the retroreflective article **100**) may be formed.
[0098] Unless otherwise indicated, all numbers expressing feature sizes, amounts, and physical properties used in the specification and claims are to be understood as being modified by the term “about”. Accordingly, unless indicated to the contrary, the numerical parameters set forth in the foregoing specification and attached claims are approximations that can vary depending upon the desired properties sought to be obtained by those skilled in the art utilizing the teachings disclosed herein.
[0099] Although specific embodiments have been illustrated and described herein, it will be appreciated by those of ordinary skill in the art that a variety of alternate and/or equivalent implementations can be substituted for the specific embodiments shown and described without departing from the scope of the present disclosure. This application is intended to cover any adaptations or variations of the specific embodiments discussed herein. Therefore, it is intended that this disclosure be limited only by the claims and the equivalents thereof.

## Claims

**1**. A retroreflective article comprising: a mesh layer comprising a plurality of interconnected portions defining a plurality of enclosed openings therebetween, a first mesh major surface, and a second mesh major surface opposite to the first mesh major surface, the plurality of interconnected portions together forming the first mesh major surface and the second mesh major surface; a bond layer comprising a plurality of bond portions at least partially spaced apart from each other by the mesh layer, wherein each of the plurality of bond portions is at least partially disposed within a corresponding enclosed opening from the plurality of enclosed openings and fixedly bonded to one or more adjacent interconnected portions from the plurality of interconnected portions of the mesh layer, and wherein the second mesh major surface is proximal to the bond layer; and a plurality of sets of optical elements corresponding to the plurality of bond portions of the bond layer, wherein each of the sets of optical elements comprises a plurality of optical elements partially embedded within a corresponding bond portion from the plurality of bond portions of the bond layer, wherein the first mesh major surface is proximal to the sets of optical elements, and wherein the sets of optical elements are spaced apart from each other by the one or more interconnected portions of the mesh layer.
**2**. The retroreflective article of claim 1, wherein each of the plurality of bond portions is spaced apart from the first mesh major surface along a thickness of the mesh layer.
**3**. The retroreflective article of claim 1, wherein the mesh layer comprises a mesh fabric.
**4**. (canceled)
**5**. (canceled)
**6**. The retroreflective article of claim 1, wherein the mesh layer has a thickness from 0.05 mm to about 2.5 mm.
**7**. (canceled)
**8**. The retroreflective article of claim 1, wherein each of the plurality of optical elements comprises a transparent microsphere.
**9**. The retroreflective article of claim 8, wherein a median diameter of the plurality of optical elements is from about 0.015 mm to about 0.11 mm.
**10**. The retroreflective article of claim 8, wherein a minimum thickness of the mesh layer is greater than a median diameter of the plurality of optical elements by a factor of at least 2.

**11**. The retroreflective article of claim 1, further comprising a reflective layer disposed adjacent to a surface of at least some of the plurality of optical elements facing the bond layer, wherein the reflective layer is at least partially disposed between the plurality of optical elements and the bond layer.
**12**. The retroreflective article of claim 11, further comprising an interlayer at least partially disposed between the plurality of optical elements and the reflective layer.
**13**. The retroreflective article of claim 11, wherein the reflective layer comprises a metal mirror or a dielectric mirror.
**14**. The retroreflective article of claim 1, further comprising an adhesive layer disposed on at least one of the second mesh major surface of the mesh layer and the bond layer opposite to the plurality of optical elements.
**15**. The retroreflective article of claim 14, wherein the adhesive layer comprises an adhesive, and wherein the adhesive is a pressure sensitive adhesive or a hot-melt adhesive.
**16**. A method of manufacturing a retroreflective article, the method comprising: providing a carrier layer; disposing a mesh layer on the carrier layer, the mesh layer comprising a plurality of interconnected portions defining a plurality of enclosed openings therebetween, a first mesh major surface, and a second mesh major surface opposite to the first mesh major surface, wherein the first mesh major surface is disposed on the carrier layer; disposing a plurality of optical elements within the plurality of enclosed openings of the mesh layer; and providing a bond layer adjacent to the plurality of optical elements within the plurality of enclosed openings of the mesh layer opposite to the carrier layer, such that the plurality of optical elements is partially embedded within the bond layer, wherein the bond layer fixedly bonds to the plurality of interconnected portions of the mesh layer.
**17**. The method of claim 16, further comprising providing a reflective layer adjacent to a surface of at least some of the plurality of optical elements prior to providing the bond layer, such that the reflective layer is at least partially disposed between the bond layer and the plurality of optical elements.
**18**. The method of claim 17, further comprising providing an interlayer on at least some of the plurality of optical elements prior to providing the reflective layer.
**19**. The method of claim 16, further comprising removing the carrier layer from the mesh layer and the plurality of optical elements.
**20**. The method of claim 16, further comprising providing an adhesive layer on at least one of the second mesh major surface of the mesh layer and the bond layer opposite to the plurality of optical elements.
**21**. The method of claim 16, wherein disposing the mesh layer on the carrier layer further comprises removably bonding the carrier layer to the mesh layer.
**22**. The method of claim 21, wherein the carrier layer comprises a liner and a carrier bonding layer bonding the liner to the mesh layer.
**23**. The method of claim 16, wherein disposing the plurality of optical elements within the plurality of enclosed openings further comprises disposing the plurality of optical elements on the carrier layer.