DIFFUSE HIGH REFLECTANCE FILM

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ABSTRACT

A diffuse reflective film including a bottom layer of reflective specular material and a top layer of polytetrafluoroethylene (PTFE) diffuser material for diffusely reflecting at least 96% of light in the portion of the electromagnetic spectrum between about 400 nanometers and about 2500 nanometers, and wherein the diffuse reflective film has a thickness of less than 1500 micrometers.
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TECHNICAL FIELD OF THE DISCLOSURE

[0001] The present disclosure relates to an improved high reflectance material and, in particular, to the creation of a composite material combining polytetrafluoroethylene (PTFE) diffuser material with thermally induced phase separation (TIPS) thin films or thin, highly reflective and specular metal films or substrates resulting in a highly lamberian, highly reflective diffuse material having significant optical benefits over currently available products.

BACKGROUND OF THE DISCLOSURE

[0002] Diffuse reflection provides reflective light luminance at many angles, in contrast to specular or mirror reflection in which light is reflected back only at an angle equal to that of the incident radiation. Typical diffuse reflectors, used for example as white standards for various light measuring test instruments, are made of white inorganic compounds (such as barium sulfate or magnesium oxide) in the form of pressed cake or ceramic tile, all of which are expensive, stiff, and brittle. Other existing diffuse reflectors include (1) microwaved particle-filled articles that depend on a difference in index of refraction of the particles, the surrounding matrix and optional air-filled voids created from stretching, and (2) microporous materials made from a sintered polytetrafluoroethylene suspension. Another useful technology for producing microporous films is thermally induced phase separation (TIPS). Vikuiti™ Enhanced Specular Reflector (ESR) is an example of a material made using TIPS and is an ultra-high reflectivity, mirror-like optical enhancement film, which is available from the Electronic Display Lighting Optical Systems Division of 3M Company (www.3M.com).

[0003] Effective but inexpensive diffuse reflective films are still needed for the many diverse light management applications that are being developed. Many such applications require that diffuse reflective films be as thin as possible, particularly when the diffuse reflective films are used in electronic displays, such as liquid crystal displays (LCD’s) incorporated into notebook computers, handheld computers, portable phones, and other electronic devices. Furthermore, improved reflective films are necessary that efficiently reflect light substantially uniformly across the ultraviolet-visible-near infrared (UV-VIS-NIR) part of the electromagnetic spectrum.

SUMMARY OF THE DISCLOSURE

[0004] The present disclosure provides a diffuse reflective film including a bottom layer of reflective specular material and a top layer of polytetrafluoroethylene (PTFE) diffuser material. The resulting film is preferably flexible and can diffuse reflect radiation substantially uniformly across the UV-VIS-NIR part of the electromagnetic spectrum, e.g., UV-VIS-NIR light having a wavelengths within the 250 to 2500 nanometer (nm) range, and more efficiently than most other known reflectors of similar thickness, e.g., greater than 96% reflective across the UV-VIS-NIR (250-2400 nanometers) part of the spectrum. The diffuse reflective film has a reduced thickness of less than 1500 micrometers, while maintaining a high absolute reflectance value. This reduced thickness allows for creation of various products having a narrow profile, such as liquid crystal display (LCD) illumination systems.

[0005] According to one aspect of the present disclosure, the top layer of PTFE diffuser material comprises Zenith™ PTFE-based diffuse reflectance film, which is available from SphereOptics-Hoffman LLC (www.sphereoptics.com).

[0006] According to another aspect of the present disclosure, the bottom layer of reflective specular material comprises a thermally induced phase separation (TIPS) layered polymer film. An example of a suitable TIPS layer polymer film is Vikuiti™ Enhanced Specular Reflector (ESR) layered polymer film, which is available from the Electronic Display Lighting Optical Systems Division of 3M Company (www.3M.com).

[0007] According to another aspect, the Zenith™ diffuse reflectance film has a thickness of not more than 1000 micrometers, while the bottom layer of reflective specular material has a thickness of not more than 500 micrometers. According to an additional aspect, an adhesive layer is provided between the Zenith™ diffuse reflectance film and the bottom layer of reflective specular material, and an adhesive layer is provided on a bottom surface of the bottom layer of reflective specular material. According to a further aspect, the Zenith™ diffuse reflectance film is placed on the more reflective surface of the bottom layer of reflective specular material (the top and bottom surfaces of the bottom layer of reflective specular material may be different in that one surface is slightly more reflective than the other surface).

[0008] The bottom layer of reflective specular material can comprise other thin, highly reflective and specular metal films or substrates, and the Zenith™ diffuse material applied to other films and substrates also has enhanced reflectivity and will yield similar results.

[0009] The present disclosure also provides an optical cavity including a light source in combination with a housing that further contains a diffuse reflector film constructed in accordance with the present disclosure (as described above) lining a portion of the cavity and partially wrapping around the light source so as to direct light from the light source into the optical cavity. The diffuse reflector film reflects light from the light source into the optical cavity, and also reflects light, including recycled light, in the optical cavity toward an open space, such as a room, or toward a viewer.

[0010] The present disclosure also provides a lamp cavity including a light source, such as a cold cathode fluorescent lamp, in combination with a housing that further contains a diffuse reflector film constructed in accordance with the present disclosure (as described above) lining a portion of the cavity facing the light source and partially wrapping around the light source.

[0011] Exemplary embodiments of the diffuse reflective film of the present disclosure have been found to be useful in a variety of structures for light management applications. For example, they have been used as a back reflector in display products, such as liquid crystal displays (LCD), flat panels, organic light emitting diodes (OLED) and architectural backlight panels. The diffuse reflective film of the present disclosure may also be used to increase the brightness of sign cabinets, light fibers, instrumentation enclosures, and light conduits. Such articles containing the diffuse reflective films of the present disclosure are further aspects of the present disclosure.
Other features and advantages of the present disclosure will be apparent from the following detailed description of the disclosure and the claims. The above summary of principles of the disclosure is not intended to describe each illustrated embodiment or every implementation of the present disclosure. The drawings and the detailed description that follow more particularly exemplify certain preferred embodiments utilizing the principles disclosed herein.

**BRIEF DESCRIPTION OF THE DRAWINGS**

**FIG. 1** is an enlarged side elevation view of a diffuse reflective film constructed in accordance with the present disclosure and including a bottom layer of reflective specular material, a top layer of polytetrafluoroethylene (PTFE) diffuser material, and a removable protective liner;

**FIGS. 2-6** are schematic diagrams of exemplary embodiments of liquid crystal display devices incorporating diffuse reflective films constructed in accordance with the present disclosure; and

**FIG. 7** schematically depicts a cross-section of a light conduit using a diffuse reflective film constructed in accordance with the present disclosure.

While principles of the disclosure are amenable to various modifications and alternative forms, specifics thereof have been shown by way of example in the drawings and will be described in detail. It should be understood, however, that the intention is not to limit the disclosure to the particular embodiments described. On the contrary, the intention is to cover all modifications, equivalents, and alternatives falling within the spirit and scope of the disclosure.

**DETAILED DESCRIPTION**

**FIG. 1** Referring to **FIG. 1**, the present disclosure provides a diffuse reflective film 10 including a bottom or back layer of reflective specular material 12 and a top or front layer 14 of polytetrafluoroethylene (PTFE) diffuser material. The resulting film 10 is preferably flexible such that it can be easily conformable to many different useful configurations, and can diffusely uniformly reflect radiation in the ultraviolet-visible-near infrared (UV-VIS-NIR) range of the electromagnetic spectrum, i.e. between 250 and 2500 nanometers (nm), efficiently. By “efficiently” it is meant, for example, greater than 96% reflective across this portion of the spectrum, than most other known reflectors of similar thickness. The diffuse reflective film 10 has a reduced thickness of less than 1000 micrometers, while maintaining a high absolute reflectance value (it should be noted that the drawing in **FIG. 1** is not to scale or proportion and is greatly enlarged to more easily illustrate the different layers). This reduced thickness allows for creation of various products having a narrowed profile, including LCD illumination systems.

In the exemplary embodiment of the present disclosure shown in **FIG. 2**, the top layer 14 of PTFE diffuser material comprises Zenith™ PTFE-based diffuse reflectance film, which is available from SphereOptics-Hoffman LLC (www.sphereoptics.com), while the bottom layer 12 of reflective specular material comprises a thermally induced phase separation (TPIS) layered polymer film. An example of a suitable TPIS layered polymer film is Vikuiti™ Enhanced Specular Reflector (ESR) layered polymer film, which is available from the Electronic Display Lighting Optical Systems Division of 3M Company (www.3M.com). Although it should be understood that the bottom layer of reflective specular material can alternatively comprise thin, highly reflective and specular metal films or substrates, and the Zenith™ diffuse material applied to other metal films and substrates also has enhanced reflectivity and will yield similar results.

**FIG. 1** An adhesive layer is provided between the Zenith™ diffuse reflectance film 14 and the Vikuiti™ ESR layered polymer film 12, and an adhesive layer is provided on a bottom surface of the Vikuiti™ ESR layered polymer film 12. A removable protective layer 16 covers bottom surface of the Vikuiti™ ESR layered polymer film 12 prior to applying the film to a desired surface for reflecting light.

**FIG. 2** The Zenith™ diffuse reflectance film 14 has a thickness of not more than 1000 micrometers, while the Vikuiti™ ESR layered polymer film 12 has a thickness of not more than 500 micrometers. The Zenith™ diffuse reflectance film 14 is placed on the more reflective surface of the Vikuiti™ ESR layered polymer film 12 (the Vikuiti™ ESR layered polymer film’s top and bottom surfaces are different in that one surface is slightly more reflective than the other surface).

**FIG. 3** The diffuse reflective film 10 of the present disclosure has a wide variety of light management applications. The diffuse reflective film 10 of the present disclosure may be used to partially line an optical cavity to increase the efficient use of light to illuminate such things as, for example, a partially transparent image that may be either static (such as a graphics film or a transparency) or switchable (such as a liquid crystal display). Thus, optical cavities that are partially lined with a diffuse reflector film 10 of the present disclosure may be used in such devices as backlight units including as liquid crystal display constructions (LCDs), lights, copying machines, projection system displays, OLED display constructions, facsimile apparatus, electronic blackboards, diffuse light standards, and photographic lights. They may also be part of a sign cabinet system, a light conduit or units containing light emitting diodes (LEDs).

**FIG. 4** The diffuse reflective film 10 of the present disclosure has been found to be especially beneficial as a back reflector in back lighting structures used for liquid crystal displays. In this type of application, the article is placed directly behind the light source which is illuminating a display. The film 10 acts to reflect back light which is not directed toward the display and ultimately a viewer. The scattering or diffuse reflection characteristics of the film back reflector also helps provide a more overall diffuse light source and more evenly lit display structure.

**FIG. 5** As used herein, the term “structure” refers to any unit or article capable of holding or supporting the diffuse reflective film 10 in place, such as, for example, a rigid or flexible frame, an awning, umbrella, backlight constructions having both static or moving images, light conduits, light boxes, LCDs, LED displays, sub-components of LCDs, sub-components of LED displays, and reflectors.

**FIG. 6** As used herein, the term “optical cavity” refers to an enclosure designed to contain a light source and direct the
light from the light source toward an object benefiting from illumination, such as a static display, a changing image or an insufficiently illuminated object. In certain implementations, the optical cavity includes a lightguide or waveguide.

[0025] Schematic figures of several structures including liquid crystal displays (LCD) and incorporating the diffuse reflective film 10 constructed in accordance with the present disclosure are shown in FIGS. 2-6. In FIG. 2, a structure 20 is shown that has a fluorescent light source 22 coupled to a plastic light guide 24. Although not shown, a diffuser, a brightness enhancing film, and a reflective polarizer film, for example, can be placed on top of the guide 24 and act to redirect and polarize the light emitted from the plastic light guide 24 towards the LCD and the viewer. If the light is not at the correct range of viewing angles, or of the correct polarization, it is reflected back towards the light guide 24. The LCD is placed on top of the films and is typically constructed of a liquid crystal sandwiched between two polarizers.

[0026] The diffuse reflective film 10 acts as a light recycler by (1) reflecting the light rejected from the reflective polarizing film and/or from the brightness enhancement film and (2) gives that light another opportunity to reach a viewer. This rejecting and recycling can occur numerous times increasing the amount of light directed towards the LCD and the viewer.

[0027] This increased optical efficiency of the diffuse reflective film 10 can be used to reflect incident light between the polarizing and/or brightness enhancement films and the diffuse reflective film 10 to increase display luminance by controlling the angles over which light is emitted. The reflected light is scattered by the diffuse reflective film 10 into all angles. The light within the transmission angles of the polarizing and/or brightness enhancement films is transmitted towards the viewer. Light in the second angular range is reflected for additional scattering.

[0028] Additionally, the diffuse reflective film 10 may be placed behind or around the light source 22, such as a cold cathode fluorescent lamp to increase light coupling efficiency into the plastic light guide 24.

[0029] In FIG. 3, another LCD display 30 is shown, containing a light guide 34 and a light source 32. A single piece of the diffuse reflective film 10 covers the bottom surface of the light guide 34, but also wraps around a portion of the light source 32. In this manner, the diffuse reflective film 10 aids in the reflection of light from the light source 32 into the light guide 34, thereby increasing the efficiency of the light guide 34 and also improving the ease of manufacture of the display 30 by forming a single, integrated diffuse reflective film 10 for the display. In addition, the improved single diffuse reflective film 10 avoids any possible loss of light between two separated, diffuse reflective films 10, such as shown in FIG. 2.

[0030] The increased optical efficiency of the diffuse reflective film 10 is used to increase the reflective efficiency of an optical cavity and/or to mix discrete wavelengths of light to make a uniform colored or white light source. In the schematic drawing of portions of an LCD device 40 shown in FIG. 4, three fluorescent lamps 42 are depicted in an optical cavity 44. All of the lamps 42 may be white or each lamp may be a selected color, such as red, green and blue. The optical cavity 44 is lined with the diffuse reflective film 10 of the present disclosure to both increase reflectance and mix the discrete colors adequately to form a white light source with good spatial light emitting uniformity to illuminate the LCD 40.

[0031] In FIG. 5, the LCD device 50 is shown with two light emitting diodes (LEDs) 52 as the light source that provides light to an optical cavity 54. The diodes 52 may be colored or white. The optical cavity 54 is lined with the diffuse reflective film 10 of the present disclosure to both increase reflectance and mix the discrete colors adequately to form a white light source with good spatial light emitting uniformity to illuminate the LCD.

[0032] The device 60 schematically shown in FIG. 6 uses a prismatic light conduit 62 as the light source in an optical cavity 64. The diffuse reflective film 10 of the present disclosure is used both in the light conduit 62 as extractors to scatter light towards the LCD and as back reflectors to reflect the light exiting around the light conduit 64 to form an efficient optical cavity.

[0033] LEDs are useful light sources for small LCD devices such as medical monitors and automotive displays. LEDs provide the advantages of small size and lower energy consumption, but they have relatively low luminance. The optical efficiency of designs using LED or OLED illumination is increased when a diffuse reflective film 10 of the present disclosure is used as a back reflector in combination with brightness enhancing and reflective polarizer films.

[0034] The diffuse reflective film 10 of the present disclosure can also be used in OLED displays, which self-emits light under voltage bias, to capture backscatter radiation from the OLED device, redirect the light towards the viewer, and enhance the brightness of the display. The diffuse reflective film 10 would be used in these cases to envelope the OLED display to capture both backscatter, side-scatter and wave-guided energy from the OLED emission.

[0035] The diffuse reflective film 10 of the present disclosure can also be used to enhance the perceived brightness of microdisplay devices by creating more efficient illumination backlights, and diffuse light illumination delivery structures (light guides and light pipes). The diffuse reflective film 10 helps to uniformly spread the light over the surface of these microdisplays where non-uniformity can result in severely degraded perception by the viewer due to the magnified optical system viewing the microdisplay.

[0036] The diffuse reflective film 10 of the present disclosure can be used in plasma flat panel displays and in rear-projection display consoles to develop and deliver an improved uniformity and panel brightness by directing more of the lost backscatter light to the viewed panel plane.

[0037] The diffuse reflective film 10 of the present disclosure can be used in architectural lighting panels and room lighting to develop and deliver an improved uniformity and panel brightness, especially where there is a need to spread light uniformly over a very large surface or area. The principle use would be as a cavity reflector or light guide for various types of sources and the diffuse reflective film 10 would be applied to large areas where the light is intended to be delivered to and efficiently reflected from that surface to create an architectural or room lighting effect.
The diffuse reflective film can also be used to develop low level laser cavity reflectors, since heat and radiation density effects will not damage the materials.

LEDs can replace fluorescent lamps as the preferred backlight source for small liquid crystal displays such as medical monitors and automotive displays. The advantage of using LEDs is their low price, small size and low energy consumption. The disadvantage of LEDs is their relatively low brightness. With the use of the diffuse reflective film of the present disclosure as a back reflector, the brightness of LED displays can be increased.

Display sign cabinets that operate more efficiently by improving brightness while requiring less electrical energy can be made using the diffuse reflective film of the present disclosure. Sign cabinets are often made of aluminum backs (generally painted white) and sides (typically unpainted) with fluorescence lights that illuminate a front film to display an image. The luminance that displays the image can be increased if the back and all four sides of the interior are covered with the diffuse reflective film of the present disclosure. Conversely, energy used to illuminate a display film can be proportionately reduced while retaining the same luminance.

The diffuse reflective film of the present disclosure is also useful in light conduits or applications wherein light is extracted from or emanates from at least a portion of the length of the hollow light conduit. The source of light for a light conduit is typically a point source such as a metal halide lamp, or in the case of rectangular display conduit a linear light source such as a fluorescent tube may be used. Typical applications are general lighting or display lighting that includes such displays as colored tubes and thin display images and signs.

Use of the diffuse reflective film of the present disclosure as extractors or back reflectors increases the lighting efficiency of a light conduit. The diffuse reflection results in a more uniform illumination.

One exemplary embodiment of a light conduit structure is shown in FIG. 7. The light conduit is surrounded by an outer shell. Inside the outer shell the diffuse reflective film of the present disclosure is placed to reflect any stray light back into the light conduit and out through the emitting surface.

The above specification is believed to provide a complete description of the manufacture and use of particular embodiments of the present disclosure. Many embodiments of the disclosure can be made without departing from the spirit and scope of the disclosure.

What is claimed is:

1. A diffuse reflective film including a bottom layer of reflective specular material and a top layer of polytetrafluoroethylene (PTFE) diffuser material for diffusely reflecting at least 96% of light within a portion of the electromagnetic spectrum between about 400 nanometers and about 2500 nanometers, and wherein the diffuse reflective film has a thickness of less than 1500 micrometers.

2. A diffuse reflective film according to claim 1, wherein the bottom layer of PTFE diffuser material comprises Zenith™ PTFE-based diffuse reflectance film.

3. A diffuse reflective film according to claim 1, wherein the bottom layer of reflective specular material comprises thermally induced phase separation (TPIS) layered polymer film.

4. A diffuse reflective film according to claim 1, wherein the top layer of PTFE diffuser material has a thickness of not more than 1000 micrometers.

5. A diffuse reflective film according to claim 1, wherein the bottom layer of reflective specular material has a thickness of not more than 500 micrometers.

6. A diffuse reflective film according to claim 1, wherein an adhesive layer is provided between the top layer of PTFE diffuser material and the bottom layer of reflective specular material.

7. A diffuse reflective film according to claim 1, wherein an adhesive layer is provided on a bottom surface of the bottom layer of reflective specular material.

8. A diffuse reflective film according to claim 1, wherein one of a top and bottom surface of the bottom layer of reflective specular material is more reflective and the top layer of PTFE diffuser material is placed on the more reflective surface.

9. A light conduit including a diffuse reflective film according to claim 1, and further comprising an outer shell and, wherein the diffuse reflective film covers at least a portion of an inner surface of the outer shell.

10. A light box including a diffuse reflective film according to claim 1, and further comprising an outer shell and, wherein the diffuse reflective film covers at least a portion of an inner surface of the outer shell.

11. A liquid crystal display including a diffuse reflective film according to claim 1, and further comprising a light guide directing light from a light source, wherein the diffuse reflective film covers at least a portion of an inner surface of the light guide.

12. A light emitting diode display including a diffuse reflective film according to claim 1, and further comprising a light guide directing light from a light source, wherein the diffuse reflective film covers at least a portion of an inner surface of the light guide.

13. An optical cavity including a diffuse reflective film according to claim 1, and further comprising a light guide directing light from a light source, wherein the diffuse reflective film covers at least a portion of an inner surface of the light guide.

14. A sign cabinet including a diffuse reflective film according to claim 1, and further comprising walls directing light from a light source, wherein the diffuse reflective film covers at least portions of inner surfaces of the walls.

15. A method of forming a diffuse reflective film, comprising:

- attaching a bottom layer of reflective specular material to a top layer of polytetrafluoroethylene (PTFE) diffuser material for diffusely reflecting at least 96% of light within the portion of the electromagnetic spectrum between about 400 and about 800 nanometers (nm); and

- providing the diffuse reflective film with a thickness of less than 1500 micrometers.
16. A method according to claim 15, wherein the top layer of PTFE diffuser material comprises Zenith™ PTFE-based diffuse reflectance film.

17. A method according to claim 15, wherein the bottom layer of reflective specular material comprises thermally induced phase separation (TIPS) layered polymer film.

18. A method according to claim 15, wherein the top layer of PTFE diffuser material has a thickness of not more than 500 micrometers.

19. A method according to claim 15, wherein the bottom layer of reflective specular material has a thickness of not more than 500 micrometers.

20. A method according to claim 15, wherein an adhesive layer is provided between the top layer of PTFE diffuser material and the bottom layer of reflective specular material.

21. A method according to claim 15, wherein the bottom layer of reflective specular material comprises Vikuiti™ Enhanced Specular Reflector (ESR) layered polymer film.

22. A method according to claim 15, wherein the bottom layer of reflective specular material comprises a metal film.

23. A diffuse reflective film according to claim 1, wherein the bottom layer of reflective specular material comprises Vikuiti™ Enhanced Specular Reflector (ESR) layered polymer film.

24. A diffuse reflective film according to claim 1, wherein the bottom layer of reflective specular material comprises a metal film.