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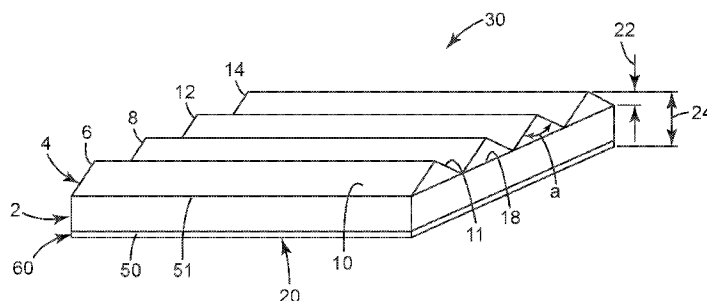


FIG. 1

(57) Abstract: Microstructured optical films are described comprising a base film substrate having two major surfaces, a polymerized microstructured surface layer comprising a plurality of prisms disposed on one major surface of the base film substrate, and a low refractive index layer disposed on the opposing surface of the base film substrate. An assembly of microstructured optical films is also described comprising a first microstructured optical film as described herein proximate a base film substrate of a second microstructured optical film as described herein.



## MICROSTRUCTURED OPTICAL FILM COMPRISING LOW REFRACTIVE INDEX LAYER DISPOSED ON BASE FILM SUBSTRATE

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### **Background**

Microstructured optical films such as brightness enhancing film typically include a microstructured surface such as a plurality of prisms disposed on a major surface of a base film substrate.

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WO 2007/053772 describes reflective polarizing films and brightness enhancing films comprising a high refractive index and/or antireflective coating.

### **Summary**

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Microstructured optical films are described comprising a base film substrate having two major surfaces, a polymerized microstructured surface layer comprising a plurality of prisms disposed on one major surface of the base film substrate, and a low refractive index layer disposed on the opposing surface of the base film substrate.

In one embodiment, the polymerized microstructured surface layer has a refractive index of at least 1.55 and the low refractive index layer comprises a fluorinated polymer.

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In another embodiment, the polymerized microstructured surface layer has a refractive index of at least 1.61 and the low refractive index layer has a refractive index that is least 0.05 less than the refractive index of the base film substrate.

In other embodiments, an assembly of microstructured optical films is described comprising a first microstructured optical film as described herein proximate a base film substrate of a second microstructured optical film as described herein.

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### **Brief Description of the Drawings**

FIG. 1 is a perspective view of an illustrative brightness enhancing film comprising a low refractive index coating disposed on a base film substrate.

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**Detailed Description**

As described in WO 2007/053772 various antireflective polymer films ("AR films") have been described.

The physical principles by which antireflection films and coatings function are known. The primary factors that contribute to antireflective properties is the difference in refractive index between the adjacent layers and the thickness of the layers. WO 2007/053772 utilizes a low refractive index layer ideally having an optical thickness on the order of one-quarter of a wavelength of light (e.g. 550 nm). The low refractive index layer is disposed on a relatively thick high refractive index layer.

Referring to Figure 1, presently described is a brightness enhancing film comprising a base film substrate 2 having two major surfaces (50 and 51). A polymerized microstructured surface layer 4 comprising a plurality of prisms is disposed on one major surface (51) of the base film substrate. A low refractive index layer (60) is disposed on the opposing surface (50) of the base film substrate. In some embodiments, the low refractive index layer is disposed directly on the base film substrate.

In other embodiments, a thin primer layer may be disposed between the base film substrate and the low refractive index layer. The thickness of the primer layer is typically at least 50, 55 or 60 nm and typically no greater than 500, 400, 300, or 200 microns.

In some embodiments, the primer layer has a refractive index of less than the base film substrate. In some embodiments, the refractive index of the primer layer is between that of the base film substrate and the low refractive index layer. For example, the base film substrate may be a polyester film having a refractive index ranging from 1.58 to 1.65 at 550 nm; whereas the primer may comprise a polyester or acrylic polymer having a refractive index of at least 1.45 or 1.50 and less than 1.65, or 1.60, or 1.55.

Various primer compositions, as known in the art, can be applied to a (e.g. light transmissive) substrate.

The primer composition may be a solvent-based primer composition or water-based primer composition.

The base polymer of the primer compositions typically comprises one or more film-forming resins. Upon evaporation of the solvent, the primer composition typically forms a continuous film. Various film-forming resins are known. Representative film-forming resins include acrylic resin(s), polyvinyl resin(s), polyester(s), polyacrylate(s),

polyurethane(s) and mixtures thereof.

The selection of the base polymer depends primarily on the composition of the (e.g. light transmissive) substrate being coating such as described in US 8,611,010.

Polyester and sulfopolyester based primers can be suitable for polyester films.

5           The primer composition may optionally contain one or more antistatic agents in an amount sufficient to provide that static dissipative properties.

          In some embodiments, the refractive index of the primer layer is index matched to the base film substrate and thus has a negligible effect on antireflective properties and improvements in gain contributed by the low refractive index layer. By index matched it  
10 is meant that the absolute value of the difference in refractive index between the primer and the base film substrate is no greater than 0.05, 0.04, 0.03, 0.02, or 0.01.

          When the low refractive index layer is disposed upon a relatively thick high refractive index layer as described in WO 2007/053772, the antireflection properties are primarily derived by the interface between these two layers.

15           Alternatively, when a low refractive index layer is disposed on a base film substrate or disposed on a thin (e.g. index matched) primer layer that is in turn disposed on the base film substrate, the antireflection properties are derived from the interface between the low refractive index layer and the base film substrate.

          However, it has been found that when a low refractive index layer is applied to the  
20 opposing surface of a base film substrate of a brightness enhancing film in the absence of a thick high refractive index layer being disposed between, the refractive index of the microstructured surface layer comprising a plurality of prisms has a substantial effect on the improvement in gain.

          An improvement in gain can be expressed by an absolute value such as an  
25 improvement of at least 0.02 or 0.03. Alternatively, an improvement in gain can be expressed as a percentage of change (e.g. increase). For example if a control film, lacking a low refractive index coating, had a single sheet relative gain of 1.76, and the same film with the low refractive index coating had an increase of 0.01, the improvement in gain would be 0.57 % ( $0.01/1.76 \times 100\%$ ). Further, if a the control film, lacking a low  
30 refractive index coating, had a single sheet relative gain of 1.76, and the same film with the low refractive index coating had an increase of 0.02, the improvement in single sheet gain would be 1.13 % ( $0.02/1.76 \times 100\%$ ). The percentage of change normalizes any

instrument variation.

However, it has been found that the presence of a low refractive index layer can improve the brightness gain significantly greater than 1.13%. For example, the percent increase in gain (X-ETavg or X-ETmin as measured according to the test method described in the examples) can be at least 1.5, 2, 2.5, 3, 3.5, or 4%.

In general, optical films are light transmissible films. Many optical films are designed to modify the wave vectors and resultant ray paths of light passing through the film. This may be accomplished for example by incorporation of a microstructured surface such as a plurality of prisms on the film surface such that the films can be used to redirect light through reflection and refraction of a (e.g. diffuse) light source.

One useful microstructure is a prismatic pattern that can act as a totally internal reflecting film for use as a brightness enhancement film.

Referring to Figure 1, microstructured optical film 30 may comprise a (e.g. preformed) base film substrate 2 and a microstructured (e.g. optical) surface layer 4. Microstructured (e.g. optical) surface layer 4 comprises a linear array of regular right prisms, identified as prisms 6, 8, 12, and 14. The height of the prisms typically ranges from about 1 to about 75 microns. Each prism, for example, prism 6, has a first facet 10 and a second facet 11. The prisms 6, 8, 12, and 14 are formed on base 2 that has a first surface 18 on which the prisms are formed and a second surface 20 that is substantially flat or planar and opposite first surface 18. By right prisms it is meant that the apex angle  $\alpha$  is typically about  $90^\circ$ . However, this angle can range from  $70^\circ$  to  $120^\circ$  and may range from  $80^\circ$  to  $100^\circ$ . Further the apexes can be sharp, rounded, flattened or truncated. For example, the ridges can be rounded to a radius of at least 0.3, 0.4, or 0.5 microns ranging up to 0.8, 0.9 or 1 micron. In some embodiments, the radius may range up to 1.5, 2, 3 or 4 microns. In yet other embodiments, the radius may range up to 5, 10 or 15 microns. The spacing between prism peaks (or pitch) can be 5 to 300 microns. For thin brightness enhancing films, the pitch is preferably 10 to 36 microns, and more preferably 18 to 24 microns. This corresponds to prism heights of preferably about 5 to 18 microns, and more preferably about 9 to 12 microns. The prism facets need not be identical, and the prisms may be tilted with respect to each other. The relationship between the total thickness of the optical article, and the height of the prisms, may vary. However, it is typically desirable to use relatively thinner optical layers with well-defined prism facets. For thin

brightness enhancing films on substrates with thicknesses close to 1 mil (20-35 microns), a typical ratio of prism height to total thickness is generally between 0.2 and 0.4.

As described in Lu (U.S. Patent No. 5,183,597) and Lu et al. (U.S. Patent No. 5,175,030), a microstructure-bearing article (e.g. brightness enhancing film) can be prepared by a method including the steps of (a) preparing a polymerizable composition; (b) depositing the polymerizable composition onto a master negative microstructured molding surface in an amount barely sufficient to fill the cavities of the master; (c) filling the cavities by moving a bead of the polymerizable composition between a preformed base film substrate and the master, at least one of which is flexible; and (d) curing the composition. The master can be metallic, such as nickel, nickel-plated copper or brass, or can be a thermoplastic material that is stable under the polymerization conditions, and that preferably has a surface energy that allows clean removal of the polymerized material from the master. One or more the surfaces of the base film can be optionally be primed or otherwise be treated to promote adhesion of the optical layer to the base.

Useful base film substrates are comprised of polymeric film materials including for example, styrene-acrylonitrile, cellulose acetate butyrate, cellulose acetate propionate, cellulose triacetate, polyether sulfone, polymethyl methacrylate, polyurethane, polyester, polycarbonate, polyvinyl chloride, polystyrene, polyethylene naphthalate, copolymers or blends based on naphthalene dicarboxylic acids, polycyclo-olefins, and polyimides.

Optionally, the base material can contain mixtures or combinations of these materials

For some optical products such as brightness enhancement films, preferred preformed polymeric films include polyethylene terephthalate (PET) and polycarbonate. Examples of useful PET films include photograde polyethylene terephthalate and MELINEX™ PET available from DuPont Films of Wilmington, Del.

In some embodiments, the base film substrate is not a (e.g. reflective) polarizing film. In other embodiments, the base film substrates act as polarizing films. Polarization of light through a film can be accomplished, for example, by the inclusion of dichroic polarizers in a film material that selectively absorbs passing light. Light polarization can also be achieved by including inorganic materials such as aligned mica chips or by a discontinuous phase dispersed within a continuous film, such as droplets of light modulating liquid crystals dispersed within a continuous film. As an alternative, a film can be prepared from microfine layers of different materials. The polarizing materials

within the film can be aligned into a polarizing orientation, for example, by employing methods such as stretching the film, applying electric or magnetic fields, and coating techniques.

Examples of polarizing films include those described in U.S. Pat. Nos. 5,825,543 and 5,783,120. The use of these polarizer films in combination with a brightness enhancement film has been described in U.S. Pat. No. 6,111,696. A second example of a polarizing film that can be used as a base are those films described in U.S. Pat. No. 5,882,774. Films available commercially are the multilayer films sold under the trade designation DBEF (Dual Brightness Enhancement Film) from 3M. The use of such multilayer polarizing optical film in a brightness enhancement film has been described in U.S. Pat. No. 5,828,488.

The base film substrate typically has a thickness of at least 0.5 mils (e.g. 0.6 mils, 0.7 mils, 0.8 mils, 0.9 mils). In some embodiments, the film thickness ranges from about 1 mil to 2 mils. In other embodiments, the base film substrate has a thickness greater than about 3 mils. For example, the thickness can range up to 4, 5, 6, 7, 8, 9, or 10 mils.

The microstructured (e.g. optical) surface layer (e.g. 4) comprises a polymerized composition or in other words a cured polymerizable composition.

The polymerizable composition is preferably a substantially solvent free polymerizable composition. "Substantially solvent free" refer to the polymerizable composition having less than 5 wt-%, 4 wt-%, 3 wt-%, 2 wt-%, 1 wt-%, and 0.5 wt-% of (e.g. organic) solvent. The concentration of solvent can be determined by known methods, such as gas chromatography. Solvent concentrations of less than 0.5 wt-% are preferred.

The components of the polymerizable composition are preferably chosen such that the composition has a low viscosity at the coating temperature. The viscosity of the polymerizable composition is less than 1000 cps and typically less than 900 cps. The viscosity of the organic component may be less than 800 cps, less than 700 cps, less than 600 cps, or less than 500 cps at the coating temperature. As used herein, viscosity is measured (e.g. at a shear rate of about 4 to 20 sec<sup>-1</sup>) with a Brookfield Viscometer. Further, the viscosity of the polymerizable composition at the coating temperature is typically at least 10 cps, at least 50 cps, or at least 100 cps.

The coating temperature typically ranges from ambient temperature, (i.e. 25°C) to 180°F (82°C). The coating temperature may be less than 170°F (77°C), less than 160°F

(71°C), less than 150°F (66°C), less than 140°F (60°C), less than 130°F (54°C), or less than 120°F (49°C). The polymerizable composition can comprise a solid component provided that the melting point in the polymerizable composition is less than the coating temperature. However, the components of the polymerizable composition are preferably liquids at ambient temperature.

The components of the polymerizable composition are preferably chosen such that the composition has a refractive index of at least 1.58, 1.59, 1.60, or 1.61. The polymerized microstructured surface also has a refractive index of at least 1.58, 1.59, 1.60, or 1.61. The polymerizable composition and polymerized microstructured surface can have a refractive index as high as 1.70 (e.g. at least 1.62, 1.63, 1.64, 1.65, 1.66, 1.67, 1.68, or 1.69). In typical embodiments, the polymerizable composition and polymerized microstructured surface comprises an organic component and high refractive index inorganic nanoparticles. The organic component typically has a lower refractive index than the total polymerizable composition. The inclusion of the high refractive index inorganic oxide nanoparticles increases the refractive index of the total polymerizable composition. High transmittance in the visible light spectrum is also typically preferred.

In some embodiments, the base film substrate has a refractive index greater than refractive index of the polymerized microstructured surface layer. In favored embodiments, the base film substrate has a refractive index of less than or equal to the polymerized microstructured surface layer.

The polymerizable composition is energy curable in time scales preferably less than five minutes (e.g. for a brightness enhancing film having a 75 micron thickness). In some embodiments, the polymerizable composition is preferably sufficiently crosslinked to provide a glass transition temperature that is typically at least 45°C. In other embodiments, the polymerizable composition provide a glass transition temperature that is less than 45°C, 40°C, 35°C, 30°C, 25°C, 20°C, 15°C, 10°C, 5°C or 0°C. The glass transition temperature can be measured by methods known in the art, such as Differential Scanning Calorimetry (DSC), modulated DSC, or Dynamic Mechanical Analysis. The polymerizable composition can be polymerized by conventional free radical polymerization methods.

The polymerizable composition comprises a mixture of ethylenically unsaturated components. The mixture preferably comprises a major amount of at least one

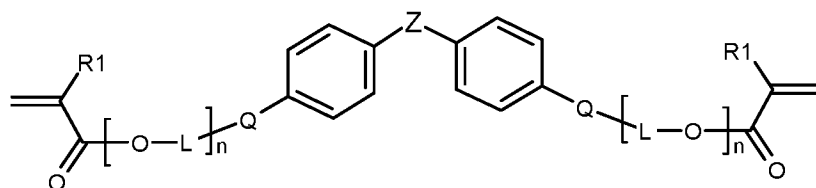


multi(meth)acrylate monomer or oligomer. In some embodiments, the multi(meth)acrylate monomer or oligomer is a di(meth)acrylate or tri(meth)acrylate. In some embodiments, the multi(meth)acrylate monomer or oligomer is aromatic. In other embodiments, the multi(meth)acrylate monomer or oligomer is non-aromatic. The multifunctional aromatic (meth)acrylate monomers and oligomers typically have a molecular weight of at least 200, 300, 400, or 450 g/mole. In some embodiments, the molecular weight is less than 1600 g/mole. It is commonly appreciated that other reaction products can be present as a byproduct of the synthesis of such multi(meth)acrylate monomers and oligomers.

In some embodiments, the polymerizable composition comprises an aromatic multi(meth)acrylate monomer and/or oligomer in an amount of at least 10 wt-% and 15 wt-%. Typically, the amount of aromatic multi(meth)acrylate monomer and/or oligomer is at least 40 wt-% and does not exceed about 60, 70 or 75 wt-% when the polymerizable composition does not contain inorganic nanoparticles. When the composition does contain inorganic nanoparticles, the polymerizable composition typically contains no greater than 40, 35, 30, or 25 wt-% aromatic multi(meth)acrylate monomer and/or oligomer.

In some embodiments, the aromatic di(meth)acrylate monomer is a bisphenol di(meth)acrylate. In yet other embodiments, the monomer is an aromatic epoxy di(meth)acrylate oligomer derived from a different starting monomer.

In some embodiments, the aromatic di(meth)acrylate monomer has the following general formula:

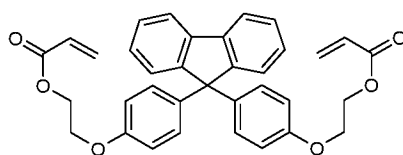


wherein Z is independently -C(CH<sub>3</sub>)<sub>2</sub>-, -CH<sub>2</sub>-, -C(O)-, -S-, -S(O)-, or -S(O)<sub>2</sub>-, each Q is independently O or S. L is a linking group. L may independently comprise a branched or linear C<sub>2</sub>-C<sub>6</sub> alkylene group and n ranges from 0 to 10. More preferably L is C<sub>2</sub> or C<sub>3</sub> and n is 0, 1, 2 or 3. The carbon chain of the alkylene linking group may optionally be substituted with one or more hydroxy groups. For example L may be -CH<sub>2</sub>CH(OH)CH<sub>2</sub>-  
Typically, the linking groups are the same. R<sub>1</sub> is independently hydrogen or methyl.

Various (meth)acrylated aromatic epoxy oligomers are commercially available. For example, (meth)acrylated aromatic epoxy, (described as a modified epoxy acrylates), are available from Sartomer, Exton, PA under the trade designation "CN118", and "CN115". (Meth)acrylated aromatic epoxy oligomer, (described as an epoxy acrylate oligomer), is available from Sartomer under the trade designation "CN2204". Further, a (meth)acrylated aromatic epoxy oligomer, (described as an epoxy novolak acrylate blended with 40% trimethylolpropane triacrylate), is available from Sartomer under the trade designation "CN112C60". One exemplary aromatic epoxy acrylate is commercially available from Sartomer under the trade designation "CN 120" (reported by the supplier to have a refractive index of 1.5556, a viscosity of 2150 at 65°C, and a T<sub>g</sub> of 60°C).

One exemplary bisphenol A ethoxylated diacrylate monomer is commercially available from Sartomer under the trade designations "SR602" (reported to have a viscosity of 610 cps at 20°C and a T<sub>g</sub> of 2°C). Another exemplary bisphenol A ethoxylated diacrylate monomer is as commercially available from Sartomer under the trade designation "SR601" (reported to have a viscosity of 1080 cps at 20°C and a T<sub>g</sub> of 60°C).

In other embodiments, the bisphenol di(meth)acrylate monomer includes additional aromatic groups such as in the case of fluorene-containing monomers. One particular fluorene-containing (meth)acrylate monomer that has been described for use as a high refractive index reactive diluent is 9,9-bis[4-(2-acryloyloxyethoxy)phenyl]fluorene (NK Ester A-BPEF), available from Shin-Nakamura. The structure of this monomer is shown as follows:



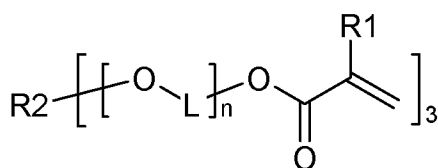
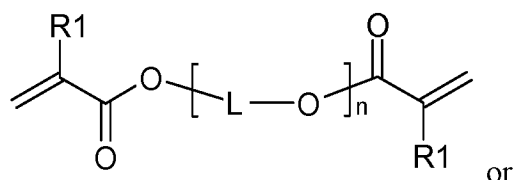
NK Ester A-BPEF

In this embodiment, Z is fluorene.

In other embodiments, the polymerizable composition is chosen to reduce damage to the prism structures upon impact. Illustrative polymerizable compositions are described in WO2014/046837; incorporated herein by reference. In this embodiment, the polymerizable composition comprises at least one non-aromatic multi-(meth)acrylate monomer comprising alkylene oxide repeat units. The alkylene repeat unit typically has the formula  $-\text{[O-L]}-$  wherein L is a linear or branched alkylene. In some embodiments, the alkylene oxide is a linear or branched  $\text{C}_2$ - $\text{C}_6$  alkylene. The non-aromatic multi-(meth)acrylate monomer typically comprises two or three (meth)acrylate groups.

The non-aromatic multi-(meth)acrylate monomer generally comprises at least three or four contiguous alkylene oxide repeat units. In some embodiments, the di or tri(meth)acrylate monomer comprises at least 5, 6, 7, 8, 9, or 10 contiguous alkylene oxide repeat units. In some embodiments, the number of contiguous alkylene oxide repeat units is no greater than 30, or 25, or 20, or 15.

In some embodiments, the non-aromatic multi-(meth)acrylate monomer may be represented by the general formula:



wherein R1 is H or methyl, R2 is a trivalent organic residue, L is independently a straight-chain or branched  $\text{C}_2$  to  $\text{C}_6$  alkylene, and n is 3 to 30.

In some embodiments, R<sub>2</sub> is a hydrocarbon residue comprising at least 3, 4, 5, or 6 carbon atoms and typically no greater than 12 carbon atoms. In some embodiments, R is a hydrocarbon residue, optionally further comprising one or more oxygen, sulfur or nitrogen atoms.

5           The non-aromatic multi-(meth)acrylate monomer comprising at least three or four contiguous alkylene oxide repeat units may comprise any combination of linear and/or branched alkylene oxide repeat units. In some embodiments, the monomer comprises solely ethylene oxide repeat units. In other embodiments, the monomer comprises solely propylene oxide repeat units. In yet other embodiments, the monomer comprises solely  
10 butylene oxide repeat units. In yet other embodiments, the monomer may comprise various combinations of such alkylene oxide repeat units. For example, the non-aromatic multi-(meth)acrylate monomer may comprise a combination of both ethylene oxide and propylene oxide repeat units.

Various non-aromatic multi-(meth)acrylate monomers comprising at least three  
15 contiguous C<sub>2</sub>-C<sub>4</sub> alkylene oxide repeat units are commercially available. Other monomers can be synthesized, such as by reaction of polyalkylene oxide polyols with acrylic acid, such as described in WO2014/011731; incorporated herein by reference.

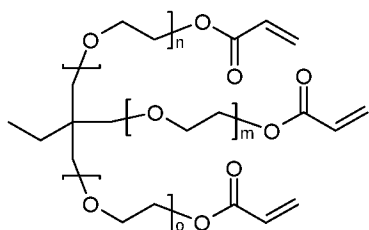
In some embodiments, a di(meth)acrylate monomer is utilized comprising 3 or 4  
20 contiguous alkylene oxide repeat units, such as ethylene oxide repeat units, propylene oxide repeat units, or a mixture thereof. The number of contiguous alkylene oxide repeat units may be no greater than 13, or 12, or 11, or 10, or 9, or 8, and in some embodiments, no greater than 7, or 6, or 5. Representative monomers, available from Sartomer USA (Exton, PA) include tetraethylene glycol diacrylate and polyethylene glycol diacrylates, such as available under the trade designations "SR268", "SR259", "SR344" and "SR610".

25           Other representative monomers include polypropylene glycol diacrylates available from Monomer-Polymer & Dajac Labs, PA, USA under the trade designation "Polypropylene Glycol 400 diacrylate".

Polyethylene and polypropylene glycol diacrylates typically comprise a mixture of molecules wherein n averages the range specified above.

30           In other embodiments, a tri(meth)acrylate monomer is utilized comprising 4 to 5 contiguous alkylene oxide repeat units, such as ethylene oxide repeat units, propylene oxide repeat units, or a mixture thereof. The number of contiguous alkylene oxide repeat

units may be no greater than 15, or 14, or 13, and in some embodiments, no greater than 12, or 9, or 10. A representative monomer includes ethoxylated trimethylol propane tri(meth)acrylate monomers, the acrylate having the following formula:



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wherein at least one of n, m or o is 3 or 4. The sum of n+m+o is typically at least 5, 6, 7, 8, 9, or 10 and in some embodiments no greater than 30.

One representative monomer of such formula, wherein the sum of n, m and o is about 15, is available from Sartomer under the trade designation "SR9035".

The concentration of the non-aromatic multi- (meth)acrylate monomer comprising alkylene oxide repeat units in the polymerizable composition is typically at least 3 wt-%, 4 wt-% or 5 wt-%. In some embodiments, the organic component is comprised solely of one or more of such non-aromatic multi- (meth)acrylate monomers. Thus, 100% of the organic component is non-aromatic multi- (meth)acrylate monomer(s) comprising at least three contiguous alkylene oxide repeat units. Since the composition also comprises at least about 20 wt-% inorganic nanoparticle and at least about 5 wt-% surface treatment, the polymerizable composition typically comprises a maximum of about 75 wt-% of the non-aromatic multi- (meth)acrylate monomer(s) comprising at least three contiguous alkylene oxide repeat units

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In yet other embodiments, the non-aromatic multi- (meth)acrylate monomer comprising alkylene oxide repeat units is combined with other (i.e. different) monomers, such as crosslinking agents and/or monofunctional diluents. In such embodiments, the polymerizable composition may comprise at least 6 wt-%, 7 wt-%, 8 wt-%, 9 wt-%, or 10 wt-% of the non-aromatic multi-(meth)acrylate monomer(s) comprising alkylene oxide repeat units and typically no greater than 50 wt-% or 45 wt-%. In some embodiments, the polymerizable composition comprises no greater than 40 wt-%, 39 wt-%, 38 wt-%, 37 wt-%, 36 wt-%, or 35 wt-% of the non-aromatic multi-(meth)acrylate monomer(s) comprising alkylene oxide repeat units.

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In some embodiments, the polymerizable composition is free of crosslinker. In some embodiments, the polymerizable composition is free of (meth)acrylate diluent. In yet other embodiments, the polymerizable composition further comprises at least one monofunctional diluent, at least one crosslinker, or combinations thereof.

5 In some embodiments, the polymerizable composition comprises a (meth)acrylate diluent having a viscosity of less than 300, 250, or 200 cps at 25°C. The (meth)acrylate diluent may have a viscosity of less than 150 cps, 100 cps, 80 cps, 60 cps, 40 cps, or 20 cps at 25°C.

10 In some embodiments, the polymerizable composition may comprise a multifunctional (meth)acrylate component as a diluent. For example, tetraethylene glycol diacrylate such as commercially available from Sartomer under the trade designation SR 268 may be utilized as a diluent.

15 In other embodiments, the polymerizable composition comprises an aromatic monofunctional (meth)acrylate as a diluent. Such diluents typically have a refractive index greater than 1.50 (e.g. at least 1.51 or 1.52). Such reactive diluents can be halogenated or non-halogenated (e.g. non-brominated). In some embodiments, the aromatic monofunctional (meth)acrylate diluent has a refractive index of at least 1.53, 1.54, 1.55, 1.56, 1.57, or 1.58 and typically no greater than 1.60.

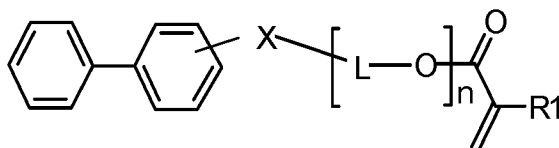
20 Suitable mono(meth)acrylate diluents include for example phenoxy ethyl (meth)acrylate; phenoxy-2-methylethyl (meth)acrylate; phenoxyethoxyethyl (meth)acrylate; 3-hydroxy-2-hydroxypropyl (meth)acrylate; benzyl (meth)acrylate; phenylthio ethyl acrylate; 2-naphthylthio ethyl acrylate; 1-naphthylthio ethyl acrylate; 2,4,6-tribromophenoxy ethyl acrylate; 2,4-dibromophenoxy ethyl acrylate; 2-bromophenoxy ethyl acrylate; 1-naphthylloxy ethyl acrylate; 2-naphthylloxy ethyl acrylate; 25 phenoxy 2-methylethyl acrylate; phenoxyethoxyethyl acrylate; 3-phenoxy-2-hydroxy propyl acrylate; 2,4-dibromo-6-sec-butylphenyl acrylate; 2,4-dibromo-6-isopropylphenyl acrylate; benzyl acrylate; phenyl acrylate; 2,4,6-tribromophenyl acrylate. Other high refractive index monomers such as pentabromobenzyl acrylate and pentabromophenyl acrylate can also be employed.

30 In some embodiments, the polymerizable composition comprises a biphenyl monomer, a benzyl monomer, or a combination thereof as a mono(meth)acrylate diluent.

Monofunctional biphenyl monomers comprise a terminal biphenyl group (wherein the two phenyl groups are not fused, but joined by a bond) or a terminal group comprising two aromatic groups joined by a linking group. The monofunctional biphenyl monomer(s) also comprise a single ethylenically unsaturated group that is preferably polymerizable by exposure to (e.g. UV) radiation. The monofunctional biphenyl monomer(s) preferably comprise a single (meth)acrylate group or single thio(meth)acrylate group. Acrylate functionality is typically preferred.

The polymerizable composition may include a single biphenyl (meth)acrylate monomer or a combination of two or more biphenyl (meth)acrylate monomers.

In one embodiment, the polymerizable composition comprises a biphenyl (meth)acrylate monomer having the general formula:



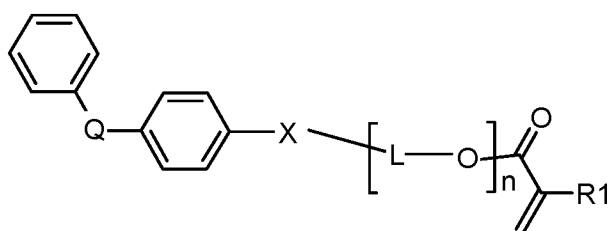
wherein R1 is H or CH<sub>3</sub>;

X is O or S;

n ranges from 0 to 10 (e.g. n is 1, 2, 3, 4, 5, 6, 7, 8, 9, or 10); and

L is an alkylene group having 1 to 5 carbon atoms (i.e. methylene, ethylene, propylene, butylene, or pentylene), optionally substituted with hydroxy.

In another embodiment, the polymerizable composition comprises a biphenyl (meth)acrylate monomer having the general formula:



wherein R1 is H or CH<sub>3</sub>;

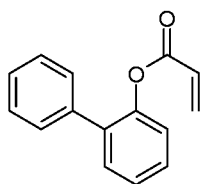
X is O or S;

Q is selected from –(C(CH<sub>3</sub>)<sub>2</sub>)–, –CH<sub>2</sub>–, –C(O)–, –S(O)–, and –S(O)<sub>2</sub>–;

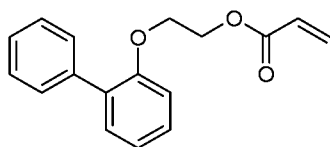
n ranges from 0 to 10 (e.g. n is 1, 2, 3, 4, 5, 6, 7, 8, 9, or 10); and

L is an alkylene group having 1 to 5 carbon atoms, optionally substituted with hydroxy.

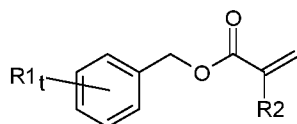
One representative biphenyl (meth)acrylate monomer, 2-phenyl-phenyl acrylate, commercially available from Toagosei Co. Ltd. of Japan under the trade designation “TO-2344” is depicted as follows:



Another biphenyl (meth)acrylate monomer is 4-(-2-phenyl-2-propyl)phenyl acrylate, available from Toagosei Co. Ltd. under the trade designation “TO-2345”. Yet another biphenyl (meth)acrylate monomer, 2-phenyl-2-phenoxyethyl acrylate, available from Toagosei Co. Ltd. under the trade designation “TO-1463” and under the trade designation “M1142” from Miwon Specialty Chemical Co. Ltd., Korea, is depicted as follows:



In another embodiment, the polymerizable composition comprises a benzyl (meth)acrylate monomer as a mono(meth)acrylate diluent. Suitable benzyl (meth)acrylate monomers are described in PCT Publication No. WO2012/158317; incorporated herein by reference. The benzyl (meth)acrylate monomer typically has the general formula:



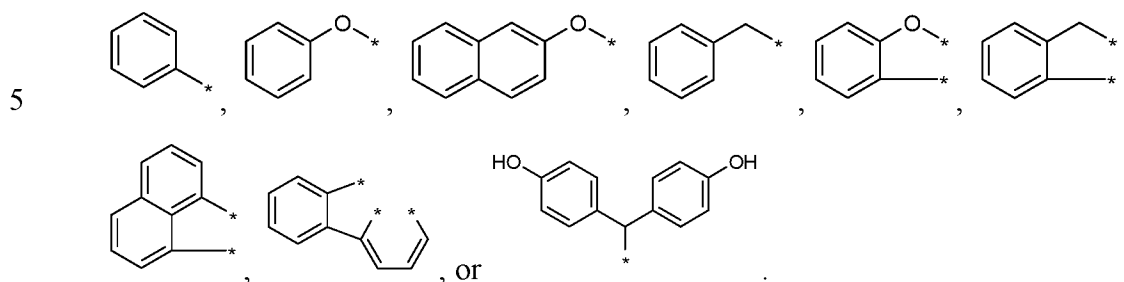
wherein at least one R1 comprises an aromatic substituent,



t is an integer from 1 to 4; and

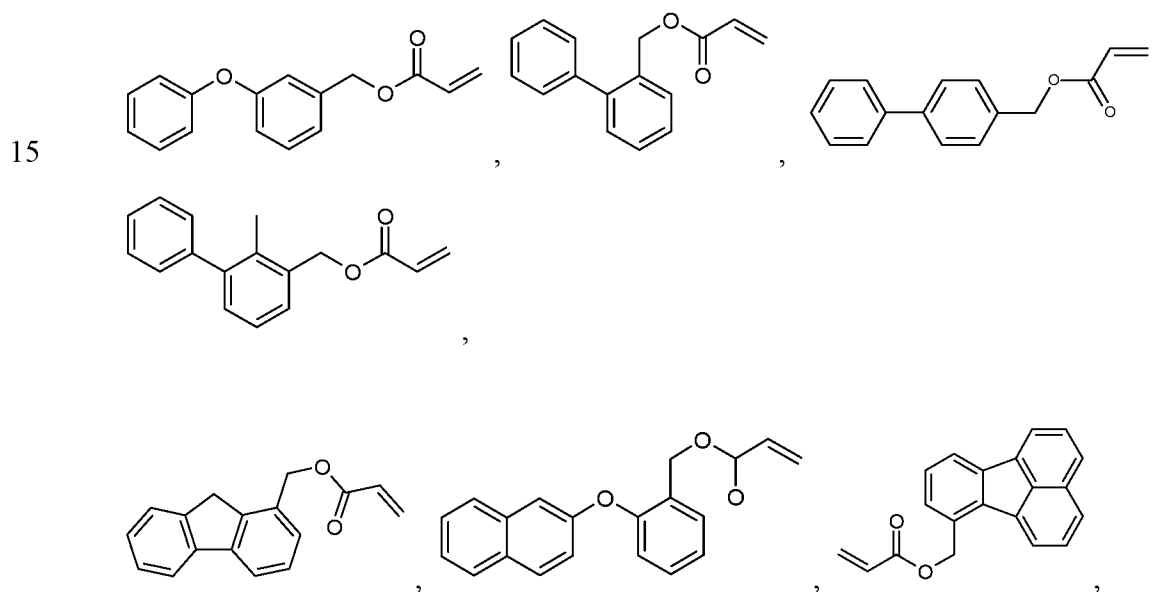
R2 is hydrogen or methyl.

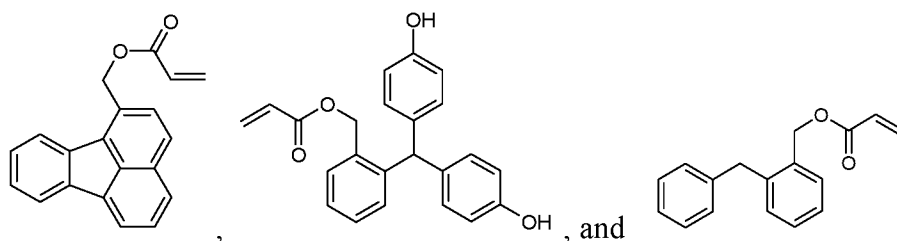
R1 may comprise various aromatic substituents such as



The aromatic substituent R1 is generally bonded to the aromatic ring of the benzyl group by at least one divalent (e.g. alkylene or ether) linking group. Hence, the aromatic ring of R1 is typically not fused to the aromatic benzyl ring, as in the case of naphthyl. In some embodiments, the aromatic substituent R1 is bonded to the aromatic benzyl ring by two or more divalent (e.g. alkylene or ether) linking groups.

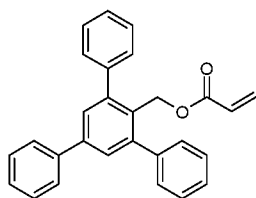
In some favored embodiments, t is 1. Representative structures include





In other embodiments,  $t$  is greater than 1. For example, in one embodiment,  $t$  is 3. One representative structure is

5



10

The polymerizable composition may comprise at least 10, 15, 20 or 25 wt-% of aromatic monofunctional (meth)acrylate diluent(s) and typically no greater than 60, 55 or 50 wt-%.

In some embodiments, the polymerizable composition may comprise at least 5 wt-% and typically no greater than 15 wt-% of a crosslinker that comprises at least three (meth)acrylate groups.

15

Suitable crosslinking agents include for example pentaerythritol tri(meth)acrylate, pentaerythritol tetra(meth)acrylate, trimethylolpropane tri(meth)acrylate, dipentaerythritol penta(meth)acrylate, dipentaerythritol hexa(meth)acrylate, trimethylolpropane ethoxylate tri(meth)acrylate, glyceryl tri(meth)acrylate, pentaerythritol propoxylate tri(meth)acrylate, and ditrimethylolpropane tetra(meth)acrylate. Any one or combination of crosslinking agents may be employed. Since methacrylate groups tend to be less reactive than acrylate groups, the crosslinker(s) are preferably free of methacrylate functionality.

20

In some embodiments, the polymerizable composition further comprises inorganic nanoparticles.

25

The total amount of inorganic nanoparticles present in the polymerizable composition is at least 20 wt-%, 25 wt-%, 30 wt-% 35 wt-% or 40 wt-%. The concentration is typically less than 70, 65 or 60 wt-%, in order that the polymerizable composition has a suitable viscosity for use in cast and cure processes of making

microstructured films. In some embodiments, the concentration is no greater than 55 or 50 wt-%. In some embodiments, the concentrations just described are the concentration of high refractive index nanoparticles. In other embodiments, the concentrations just described are the concentration of a combination of higher refractive index nanoparticles and lower refractive index nanoparticles, such as silica.

The size of such particles is chosen to avoid significant visible light scattering. It may be desirable to employ a mixture of inorganic oxide particle types to optimize an optical or material property and to lower total composition cost. The surface modified colloidal nanoparticles can be oxide particles having a (e.g. unassociated) primary particle size or associated particle size of greater than 1 nm, 5 nm or 10 nm. The primary or associated particle size is generally and less than 100 nm, 75 nm, or 50 nm. Typically the primary or associated particle size is less than 40 nm, 30 nm, or 20 nm. It is preferred that the nanoparticles are unassociated. Their measurements can be based on transmission electron microscopy (TEM).

The high refractive index nanoparticles typically have a refractive index of at least 1.68. Such nanoparticles typically comprise or consist of metal oxides such as, for example, alumina, zirconia, titania, mixtures thereof, or mixed oxides thereof.

Zirconia and titania nanoparticles can have a particle size from 5 to 50 nm, or 5 to 15 nm, or 8 nm to 12 nm. Zirconia nanoparticles can be present in the durable article or optical element in an amount of at least 10, 15, 20, 25, 30, 35, or 40 wt.-% and in some embodiments no greater than 70 or 65 wt.-%. Zirconias for use in composition and articles of the invention are available from Nalco Chemical Co. under the trade designation "Nalco OOSOO8" and from Buhler AG Uzwil, Switzerland under the trade designation "Buhler zirconia Z-WO sol".

The zirconia particles can be prepared using hydrothermal technology as described in PCT Publication WO2009/085926 and U.S. Patent No. 7,241,437; incorporated herein by reference. Once formed, the nanoparticles typically comprise adsorbed volatile acid (i.e. monocarboxylic acids having six or less carbon atoms) such as acetic acid.

The inorganic nanoparticles are generally surface modified. Surface modification involves attaching surface modification agents to inorganic oxide (e.g. zirconia) particles to modify the surface characteristics. The overall objective of the surface modification of the inorganic particles is to provide compositions with homogeneous components and

preferably a low viscosity that can be prepared into films (e.g. using cast and cure processes) with high brightness.

The nanoparticles are often surface modified to improve compatibility with the organic component. The surface modified nanoparticles are often non-associated, non-agglomerated, or a combination thereof in the organic component. The resulting light management films that contain these surface modified nanoparticles tend to have high optical clarity and low haze. The addition of the high refractive index surface modified nanoparticles, such as zirconia, can increase the gain of brightness enhancement film compared to films that contain only polymerized organic material.

The monocarboxylic acid (i.e., containing one carboxylic acid group per molecule) surface treatments may be represented by the formula A-B where the A group is a monocarboxylic acid group capable of attaching to the surface of a (e.g. zirconia or titania) nanoparticle, and B is a compatibilizing group that comprises a variety of different functionalities. The carboxylic acid group can be attached to the surface by adsorption and/or formation of an ionic bond. The compatibilizing group B is generally chosen such that it is compatible with the polymerizable composition of the (e.g. brightness enhancing) microstructured optical article. The compatibilizing group B can be reactive or nonreactive and can be polar or non-polar.

The compatibilizing group B is preferably reactive such that it can copolymerize with the organic component of the (e.g. brightness enhancing) microstructured optical article. For example, free radically polymerizable groups such as (meth)acrylate compatibilizing groups can copolymerize with (meth)acrylate functional organic monomers to generate brightness enhancement articles with good homogeneity.

Surface modified nanoparticles can be substantially fully condensed. Fully condensed nanoparticles (with the exception of silica) typically have a degree of crystallinity (measured as isolated metal oxide particles) greater than 55%, preferably greater than 60%, and more preferably greater than 70%. For example, the degree of crystallinity can range up to about 86% or greater. The degree of crystallinity can be determined by X-ray diffraction techniques. Condensed crystalline (e.g. zirconia) nanoparticles have a high refractive index whereas amorphous nanoparticles typically have a lower refractive index.

In some embodiments, as described in U.S. Patent Application Publication No.

2011/0227008, incorporated herein by reference, (e.g. zirconia) inorganic nanoparticles described are surface modified with a surface treatment comprising a compound comprising a carboxylic acid end group and a C<sub>3</sub>-C<sub>16</sub> ester units such as C<sub>3</sub>-C<sub>8</sub> ester repeat units or at least one C<sub>6</sub>-C<sub>16</sub> ester unit.

5           The surface modification of the particles in the colloidal dispersion can be accomplished in a variety of ways. The process generally involves the mixture of an inorganic particle dispersion with surface modifying agents. Optionally, a co-solvent can be added, such as for example, 1-methoxy-2-propanol, ethanol, isopropanol, ethylene glycol, N,N-dimethylacetamide and 1-methyl-2-pyrrolidinone. The co-solvent can enhance the  
10           solubility of the surface modifying agents as well as the surface modified particles. The mixture comprising the inorganic sol and surface modifying agents is subsequently reacted at room or an elevated temperature, with or without mixing.

          The surface modified particles can then be incorporated into the curable (i.e. polymerizable) compositions in various methods. In a preferred aspect, a solvent  
15           exchange procedure is utilized whereby a polymerizable organic component are added to the surface modified sol, followed by removal of the water and co-solvent (if used) via evaporation, thus leaving the particles dispersed in the polymerizable organic component. The evaporation step can be accomplished for example, via distillation, rotary evaporation or oven drying. In another aspect, the surface modified particles can be extracted into a  
20           water immiscible solvent followed by solvent exchange, if so desired. Alternatively, another method for incorporating the surface modified nanoparticles in the polymerizable component involves the drying of the modified particles into a powder, followed by the addition of the polymerizable organic component into which the particles are dispersed. The drying step in this method can be accomplished by conventional means suitable for  
25           the system, such as, for example, oven drying or spray drying.

          The UV curable polymerizable compositions comprise at least one photoinitiator. A single photoinitiator or blends thereof may be employed in the brightness enhancement film of the invention. In general the photoinitiator(s) are at least partially soluble (e.g. at the processing temperature) and substantially colorless after being polymerized. The  
30           photoinitiator may be (e.g. yellow) colored, provided that the photoinitiator is rendered substantially colorless after exposure to the UV light source.

Suitable photoinitiators include monoacylphosphine oxide and bisacylphosphine oxide. Commercially available mono or bisacylphosphine oxide photoinitiators include 2,4,6-trimethylbenzoyldiphenylphosphine oxide, commercially available from BASF (Charlotte, NC) under the trade designation "Lucirin TPO"; ethyl-2,4,6-  
5 trimethylbenzoylphenyl phosphinate, also commercially available from BASF under the trade designation "Lucirin TPO-L"; and bis (2,4,6-trimethylbenzoyl)-phenylphosphine oxide commercially available from Ciba Specialty Chemicals under the trade designation "Irgacure 819". Other suitable photoinitiators include 2-hydroxy-2-methyl-1-phenyl-  
10 propan-1-one, commercially available from Ciba Specialty Chemicals under the trade designation "Darocur 1173" as well as other photoinitiators commercially available from Ciba Specialty Chemicals under the trade designations "Darocur 4265", "Irgacure 651", "Irgacure 1800", "Irgacure 369", "Irgacure 1700", and "Irgacure 907".

The photoinitiator can be used at a concentration of about 0.1 to about 10 weight percent. More preferably, the photoinitiator is used at a concentration of about 0.5 to  
15 about 5 wt-%. Greater than 5 wt-% is generally disadvantageous in view of the tendency to cause yellow discoloration of the brightness enhancing film. Other photoinitiators and photoinitiator may also suitably be employed as may be determined by one of ordinary skill in the art.

Surfactants such as fluorosurfactants and silicone based surfactants can optionally  
20 be included in the polymerizable composition to reduce surface tension, improve wetting, allow smoother coating and fewer defects of the coating, etc.

The opposing surface of the base film substrate comprises a low refractive index (e.g. fluorinated) layer. Without intending to be bound by theory, it is surmised that the low refractive index layer decreases the surface reflections of the base film substrate or in  
25 other words provide antireflection properties to the base film substrate. However, surprisingly there is a greater increase in gain surmised to be due to the adjacent high refractive index microstructured surface layer. Further, the thickness of the low refractive index (e.g. fluorinated) layer that can provide a peak brightness gain typically has an optical thickness of an even multiple of  $\frac{1}{4}$  wave.

30 The low refractive index layer has a thickness ranging from 50 nm to 1000 nm. In some embodiments, the low refractive index layer has a thickness of at least 120, 125, or 130 nm. In some embodiments, the low refractive index layer has a thickness of at no

greater than 800, 700, 600, 500, 400 or 300 nm.

The low refractive index (e.g. fluorinated) layer has a refractive index that differs from the base film substrate by at least 0.10, 0.15, 0.20, or 0.25. In some embodiments, such as when the base film substrate is PET, the low refractive index (e.g. fluorinated) layer has a refractive index of no greater than 1.55, or 1.50, or 1.45, or 1.40, or 1.35.

When the low refractive index (e.g. fluorinated) layer has a refractive index of greater than about 1.45, the low refractive index layer may comprise a non-fluorinated material. However, when the low refractive index layer has a refractive index of less than 1.45, the low refractive index layer typically comprises a fluorinated polymer.

The fluorinated polymer typically has a molecular weight greater than 20,000 grams/mole. The fluorinated polymer comprises hydrogen atoms as well as fluorine atoms along the carbon backbone of the polymer. The fluorinated polymer typically comprise at least 50%, 60%, or even 70% of amount of fluorine atoms by weight along the carbon backbone of the polymer; and at most 75 or 76 of amount of fluorine atoms by weight along the carbon backbone of the polymer.

In some embodiments, the low refractive index composition comprises at least one (e.g. free-radically polymerizable) fluoropolymer. A general description and preparation of these classes of fluoropolymers can be found in *Encyclopedia Chemical Technology, Fluorocarbon Elastomers*, Kirk-Othmer (1993), or in *Modern Fluoropolymers*, J. Scheirs Ed, (1997), J Wiley Science, Chapters 2, 13, and 32. (ISBN 0-471-97055-7).

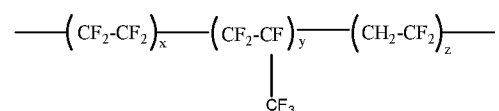
Fluoropolymers are general derived from one or more fluorinated monomer(s) such as tetrafluoroethylene (TFE), vinyl fluoride (VF), vinylidene fluoride (VDF), hexafluoropropylene (HFP), pentafluoropropylene, trifluoroethylene, trifluorochloroethylene (CTFE), perfluorovinyl ethers (including perfluoroallyl vinyl ethers and perfluoroalkoxy vinyl ethers), perfluoroallyl ethers (including perfluoroalkyl allyl ethers and perfluoroalkoxy allyl ethers), perfluoroalkyl vinyl monomers, and combinations thereof.

In some embodiments, the fluoropolymer is formed from the constituent monomers known as tetrafluoroethylene ("TFE"), hexafluoropropylene ("HFP"), and vinylidene fluoride ("VDF," "VF2,"). The monomer structures for these constituents are shown below:



The fluoropolymers preferably comprise at least two of the constituent monomers (HFP and VDF), and more preferably all three of the constituents monomers in varying molar amounts. Additional monomers not depicted in (1), (2) or (3) but also useful include perfluorovinyl ether monomers of the general structure  $\text{CF}_2=\text{CF}-\text{OR}_f$ , wherein  $\text{R}_f$  can be a branched or linear perfluoroalkyl radicals of 1-8 carbons and can itself contain additional heteroatoms such as oxygen. Specific examples are perfluoromethyl vinyl ether, perfluoropropyl vinyl ethers, perfluoro(3-methoxy-propyl) vinyl ether. Additional examples are found in Worm (WO 00/12574), assigned to 3M, and in Carlson (U.S. Patent No. 5,214,100).

Various fluoroplastics and fluoroelastomers are known such as described in US3929934. In some embodiments, the elastomers have the general formula:



wherein x, y and z are expressed as molar percentages. In some embodiments, x, y, and z are chosen such that the elastomer comprises no greater than 40 or 35 wt.-% TFE, no greater than 25 wt.-% HFP and no greater than 70, 65, or 60 wt.-% VDF. In other embodiments, the fluoroelastomer may be a copolymer comprising no more than 80, 70 or 60 wt.-% VDF and no more than 60, 50, or 40 wt.-% HFP.

For improved durability, the fluoropolymer may be polymerized in the presence of a chain transfer agent and/or halogen-containing cure site monomers and/or halogenated endgroups to introduce cure sites into the fluoropolymer. These halogen groups provide reactivity towards the other components of coating mixture and facilitate the formation of the polymer network. Useful halogen-containing monomers are well known in the art and typical examples are found in WO2014/179432.



Optionally halogen cure sites can be introduced into the polymer structure via the use of halogenated chain transfer agents which produce fluoropolymer chain ends that contain reactive halogen endgroups. Such chain transfer agents ("CTA") are well known in the literature and typical examples are: Br-CF<sub>2</sub>CF<sub>2</sub>-Br, CF<sub>2</sub>Br<sub>2</sub>, CF<sub>2</sub>I<sub>2</sub>, CH<sub>2</sub>I<sub>2</sub>. Other  
5 typical examples are found in U.S. Patent No. 4,000,356 to Weisgerber.

In another embodiment, the fluoropolymer can be rendered reactive by dehydrofluorinated by any method that will provide sufficient carbon-carbon unsaturation of the fluoropolymer to create increased bond strength between the fluoropolymer and a hydrocarbon substrate or layer. The dehydrofluorination process is a well-known process  
10 to induced unsaturation and it is used most commonly for the ionic crosslinking of fluoroelastomers by nucleophiles such as diphenols and diamines. This reaction is characteristic of VDF containing elastomers. Furthermore, such a reaction is also possible with primary and secondary aliphatic monofunctional amines and will produce a DHF-fluoropolymer with a pendent amine side group.

In some embodiments, the low refractive index layer comprises a fluoropolymer, an amino organosilane ester coupling agent or its ester equivalent, optionally in combination with a multi-olefinic crosslinker, such as described in US 7,323,514;  
15 incorporated herein by reference. Such multi-olefinic crosslinker may be the same as the previously described crosslinker of the polymerizable composition of the microstructured surface layer. The concentration of crosslinker in the low refractive index composition is  
20 generally at least 5 wt-%, or 10 wt-%, or 15 wt-% and no greater than about 40 wt-%. In some embodiments, the concentration of crosslinker in the low refractive index layer is generally no greater than about 25 wt-%.

In another embodiment, the low refractive index layer comprises a fluorinated polymer that comprises the reaction product of various-fluorinated mono- and multi-  
25 (meth)acrylate compounds. Such materials generally comprises free-radically polymerizable moieties in combination with (per)fluoropolyether moieties, (per)fluoroalkyl moieties, and (per)fluoroalkylene moieties. Within each of these classes are species having a high fluorine content, (e.g. of at least 25 wt-%). Other species within  
30 each class, having fluorine content less than 25 wt-%, can be employed as auxillary components. When the free-radically polymerizable moieties are (meth)acrylate moieties, such fluorinated polymers may be characterized as fluorinated (meth)acrylic polymers.

In one embodiment, the low refractive index layer comprising the reaction product of a polymerizable organic component comprising a free-radically polymerizable fluorinated polymeric intermediate comprising polymeric species having a hyperbranched structure as described in WO2007/146509; incorporated herein by reference. The free-  
5 radically polymerizable fluorinated polymeric intermediate comprises the reaction product of i) at least one multi-functional free-radically polymerizable material having a fluorine content of at least 25 wt-%, and ii) optionally at least one multi-functional free-radically polymerizable material having a fluorine content ranging from 0 to less than 25 wt-%, wherein the total amount of multi-functional materials is at least about 25 wt-% based on  
10 wt-% solids of the polymerizable organic component. The low refractive index layer further comprises the reaction product of at least one fluorinated free-radically polymerizable material.

The low refractive index layer prepared from various fluorinated mono- and multi-  
(meth)acrylate compounds also typically comprises a (e.g. multi-olefinic) crosslinker at  
15 the same concentrations previously described.

For improved durability, the low refractive index surface layer may further comprise inorganic nanoparticles having a refractive index of less than 1.50. Various low refractive index inorganic oxides particles are known such as metal oxides, metal nitrides, and metal halides (e.g. fluorides). Preferred low refractive index particle include colloidal  
20 silica, magnesium fluoride, and lithium fluoride. Silicas for use in the low refractive index composition are commercially available from Nalco Chemical Co., Naperville, IL under the trade designation "Nalco Collodial Silicas" such as products 1040, 1042, 1050, 1060, 2327 and 2329. Suitable fumed silicas include for example, products commercially available from DeGussa AG, (Hanau, Germany) under the trade designation, "Aerosil  
25 series OX-50", as well as product numbers -130, -150, and -200. Fumed silicas are also commercially available from Cabot Corp., Tuscola, I, under the trade designations CAB-O-SPERSE 2095", "CAB-O-SPERSE A105", and "CAB-O-SIL M5".

The fluorinated component(s) of the low refractive index layer can provide low surface energy. The surface energy of the low index coating composition can be  
30 characterized by various methods such as contact angle and ink repellency. The static contact angle with water of the cured low refractive index layer is typically at least 80°. More preferably, the contact angle is at least 90° and most preferably at least 100°.

Alternatively, or in addition thereto, the advancing contact angle with hexadecane is at least 50° and more preferably at least 60°. Low surface energy is amenable to anti-soiling and stain repellent properties as well as rendering the exposed surface easy to clean.

The low refractive index layer may have a gloss or matte surface. Matte surface layers typically have lower transmission and higher haze values than typical gloss films. For example, the haze of a matte surface layer is generally at least 5%, 6%, 7%, 8%, 9%, or 10% as measured according to ASTM D1003. Gloss surfaces typically have a gloss of at least 130 as measured according to ASTM D 2457-03 at 60 °; whereas matte surfaces have a gloss of less than 120.

The surface can be roughened or textured to provide a matte surface. This can be accomplished in a variety of ways as known in the art including embossing the low refractive index surface with a suitable tool that has been bead-blasted or otherwise roughened, as well as by curing the composition against a suitable roughened master as described in U.S. Pat. Nos. 5,175,030 (Lu et al.) and 5,183,597 (Lu).

In yet another aspect, a low refractive index (e.g. surface) layer may be provided on a matte preformed film as the base film substrate (e.g. 2). An illustrative matte films are commercially available from U.S.A. Kimoto Tech, Cedartown, GA under the trade designation "N4D2A".

Matte low refractive index coatings can also be prepared by adding a suitably sized particle filler such as silica sand or glass beads to the composition. Such matte particles are typically substantially larger than the surface modified low refractive index particles. For example the average particle size typically ranges from about 1 to 10 microns. The concentration of such matte particles may range from at least 2 wt-% to about 10 wt-% or greater. At concentrations of less than 2 wt-% (e.g. 1.8 wt-%, 1.6 wt-%, 1.4 wt-%, 1.2 wt-%, 1.0 wt-%, 0.8 wt-%, 0.6 wt-%, the concentration is typically insufficient to produce the desired reduction in gloss (which also contributes to an increase in haze). However, durable antireflective films can be provided in the absence of such matte particles.

The low refractive index layer may be prepared from a coating composition that comprises the fluorinated polymers and/or polymerizable materials utilized to make the fluorinated polymer in a compatible organic solvent at a concentration of about 1 to 10 percent solids.

A single organic solvent or a blend of solvents can be employed. Although various

fluorinated solvents could be employed, in some embodiments compatible low refractive index coating compositions are prepared that are free of fluorinated solvents.

Depending on the material employed, suitable solvents include alcohols such as isopropyl alcohol (IPA) or ethanol; ketones such as methyl ethyl ketone (MEK), methyl isobutyl ketone (MIBK), diisobutyl ketone (DIBK); cyclohexanone, or acetone; aromatic hydrocarbons such as toluene; isophorone; butyrolactone; N-methylpyrrolidone; tetrahydrofuran; esters such as lactates, acetates, including propylene glycol monomethyl ether acetate such as commercially available from 3M under the trade designation "3M Scotchcal Thinner CGS10" ("CGS10"), 2-butoxyethyl acetate such as commercially available from 3M under the trade designation "3M Scotchcal Thinner CGS50" ("CGS50"), diethylene glycol ethyl ether acetate (DE acetate), ethylene glycol butyl ether acetate (EB acetate), dipropylene glycol monomethyl ether acetate (DPMA), iso-alkyl esters such as isohexyl acetate, isoheptyl acetate, isooctyl acetate, isononyl acetate, isodecyl acetate, isododecyl acetate, isotridecyl acetate or other iso-alkyl esters; combinations of these and the like.

The method of forming the low refractive index layer on the base film substrate may include providing a preformed base film substrate and providing a layer of a low index composition coupled to the base film substrate. The low refractive index coating may be applied directly to the base preformed film or primer layer. Alternatively the low refractive index coating composition may be applied to a release layer and subsequently transferred from the release layer to the base preformed film using a thermal transfer or photoradiation.

The low refractive index coating can be applied as a single or multiple layers using conventional film application techniques. Although it is usually convenient for the film substrate to be in the form of a roll of continuous web, the coatings may be applied to individual sheets.

Thin films can be applied using a variety of techniques, including dip coating, forward and reverse roll coating, wire wound rod coating, and die coating. Die coaters include knife coaters, slot coaters, slide coaters, fluid bearing coaters, slide curtain coaters, drop die curtain coaters, and extrusion coaters among others. Many types of die coaters are described in the literature such as by Edward Cohen and Edgar Guttoff, *Modern Coating and Drying Technology*, VCH Publishers, NY 1992, ISBN 3-527-28246-7 and

Gutoff and Cohen, *Coating and Drying Defects: Troubleshooting Operating Problems*, Wiley Interscience, NY ISBN 0-471-59810-0.

The low refractive index coating is dried in an oven to remove the solvent. For improved durability, the low refractive index coating can be cured for example by exposure ultraviolet radiation using an H-bulb or other lamp at a desired wavelength, preferably in an inert atmosphere (less than 50 parts per million oxygen).

The low refractive index layer may be covered by a removable release liner to protect the low refractive index layer until the film is converted or assembled into an illuminated display device.

In some embodiments, a first microstructured optical film (e.g. brightness enhancing film) is proximate a second microstructured optical film (e.g. brightness enhancing film). By proximate, it is meant sufficiently near. Proximate can include the first microstructured optical film being in contact with the second optical film such as by the films merely being stacked together or the films may be attached by various means. The films may be attached by mechanical means, chemical means, thermal means, or a combination thereof. Chemical means includes various pressure sensitive, solvent-based, and hot melt adhesives as well as two-part curable adhesive compositions that crosslink upon exposure to heat, moisture, or radiation. Thermal means includes for example a heated embossed roller, radio frequency (RF) welding, and ultrasonic welding. The optical films may be attached (e.g. continuously) across the entire plane of the films, at only select points, or at only the edges. Alternatively, the proximate optical films may be separated from each other with an air interface. The air interface may be created by increasing the thickness of either or both optical films at the periphery, such as by application of an adhesive. When the films are stacked rather than laminated together, the air interface between the optical films may be only a few microns.

In such assemblies, the microstructured surface of the bottom film is preferably disposed proximate the unstructured surface of the top film. The prisms of the films are generally aligned parallel in one principal direction, the prisms being separated by grooves. It is generally preferred to align the prisms (or grooves) of the second (e.g. bottom) microstructured optical film in a stack such that the prisms are substantially orthogonal to the prisms of the first (e.g. top) film. However, other alignments can also be employed. For example, the prisms of the second optical film may be positioned

relative to the prisms of the second optical film such that the intersection of grooves or prisms form angles ranging from about 70° to about 120°.

By providing a low refractive index layer on a base film substrate comprising a high refractive index polymerized microstructured surface layer comprising a plurality of prisms, the assembly of first and second brightness enhancing films can provide a, improvement in gain of greater than 0.02. For example, the improvement in gain (i.e. X-ETavg or X-ETmin) can be at least 0.03, 0.04, 0.05, 0.06, 0.07, 0.08, 0.09, or 0.10 or greater. In improvement in X-ETmin can be even greater. For example, the improvement X-ETmin can be at least 0.11, 0.12, 0.13, 0.14, 0.15, 0.16, 0.17, or greater.

The brightness enhancing film(s) can be utilized in a variety of illuminated display devices such as liquid crystal displays ("LCDs") and light emitting diode ("LEDs") displays such as cell phones (including Smart phones), wearable (e.g. wrist) devices, car navigation systems, global positioning systems, depth finders, computer monitors, notebook and tablet computer displays.

Definitions of terms used within the present description:

"Index of refraction," or "refractive index," refers to the absolute refractive index of a material (e.g., a monomer) that is understood to be the ratio of the speed of electromagnetic radiation in free space to the speed of the radiation in that material. The refractive index can be measured using known methods and is generally measured using an Abbe refractometer in the visible light region (available commercially, for example, from Fisher Instruments of Pittsburgh, PA). It is generally appreciated that the measured index of refraction can vary to some extent depending on the instrument.

"(Meth)acrylate" refers to both acrylate and methacrylate compounds.

"Polymerizable composition" refers to the total composition including the organic component that comprises at least one polymerizable monomer and the optional inorganic nanoparticles.

"Organic component" refers to all of the components of the composition except for the inorganic nanoparticles and nanoparticle surface modifier(s). For embodiments wherein the polymerizable composition is free of inorganic nanoparticles, the organic component and polymerizable composition are the same.

5

The term "nanoparticles" is defined herein to mean particles (primary particles or associated primary particles) with a diameter less than about 100 nm.

10

"Surface modified colloidal nanoparticle" refers to nanoparticles each with a modified surface such that the nanoparticles provide a stable dispersion.

15

"Stable dispersion" is defined herein as a dispersion in which the nanoparticles do not agglomerate after standing for a period of time, such as about 24 hours, under ambient conditions - e.g. room temperature (about 20-22° C.), atmospheric pressure, and no extreme electromagnetic forces.

20

"Aggregation" refers to a strong association between primary particles that may be chemically bound to one another. The breakdown of aggregates into smaller particles is difficult to achieve.

25

"Agglomeration" refers to a weak association between primary particles which may be held together by charge or polarity and can be broken down into smaller entities.

"Primary particle size" refers to the mean diameter of a single (non-aggregate, non-agglomerate) particle.

30

The recitation of numerical ranges by endpoint includes all number subsumed within that range (e.g. to the degree of precision for the numerical endpoint). For example a relative gain of greater than 1.78 and less than 2.05 includes 1.79, 1.80, 1.81, 1.82, etc., up to 2.04.

Each of the patents referenced herein are incorporated by reference in their entirety. Advantages of the invention are further illustrated by the following examples, but the particular materials and amounts thereof recited in the examples, as well as other conditions and details, should not be construed to unduly limit the invention. All percentages and ratios herein are by weight unless otherwise specified.

## EXAMPLES

### Test Methods

#### Gain Test Method

Optical performance of the films was measured using a SpectraScan™ PR-650 SpectraColorimeter with an MS-75 lens, available from Photo Research, Inc, Chatsworth, CA. The films were placed on top of a diffusely transmissive hollow light box. The diffuse transmission and reflection of the light box can be described as Lambertian. The light box was a six-sided hollow cube measuring approximately 12.5cm x 12.5cm x 11.5cm (LxWxH) made from diffuse PTFE plates of ~6mm thickness. One face of the box is chosen as the sample surface. The hollow light box had a diffuse reflectance of ~0.83 measured at the sample surface (e.g. ~83%, averaged over the 400-700 nm wavelength range, measurement method described below). During the gain test, the box is illuminated from within through a ~1 cm circular hole in the bottom of the box (opposite the sample surface, with the light directed towards the sample surface from the inside). This illumination is provided using a stabilized broadband incandescent light source attached to a fiber-optic bundle used to direct the light (Fostec DCR-II with ~1 cm diameter fiber bundle extension from Schott-Fostec LLC, Marlborough MA and Auburn, NY). A standard linear absorbing polarizer (such as Melles Griot 03 FPG 007) is placed between the sample box and the camera. The camera is focused on the sample surface of the light box at a distance of ~34cm and the absorbing polarizer is placed ~2.5cm from the camera lens. The luminance of the illuminated light box, measured with the polarizer in place and no sample films, was  $>150 \text{ cd/m}^2$ . The sample luminance is measured with the PR-650 at normal incidence to the plane of the box sample surface when the sample films are placed parallel to the box sample surface, the sample films being in general contact



with the box. The relative gain is calculated by comparing this sample luminance to the luminance measured in the same manner from the light box alone. The entire measurement was carried out in a black enclosure to eliminate stray light sources.

The diffuse reflectance of the light box was measured using a 15.25 cm (6 inch) diameter Spectralon-coated integrating sphere, a stabilized broadband halogen light source, and a power supply for the light source all supplied by Labsphere (Sutton, NH). The integrating sphere had three opening ports, one port for the input light (of 2.5cm diameter), one at 90 degrees along a second axis as the detector port (of 2.5 cm diameter), and the third at 90 degrees along a third axis (i.e. orthogonal to the first two axes) as the sample port (of 5cm diameter). A PR-650 Spectracolorimeter (same as above) was focused on the detector port at a distance of ~38cm. The reflective efficiency of the integrating sphere was calculated using a calibrated reflectance standard from Labsphere having ~99% diffuse reflectance (SRT-99-050). The standard was calibrated by Labsphere and traceable to a NIST standard (SRS-99-020-REFL-51). The reflective efficiency of the integrating sphere was calculated as follows:

$$\text{Sphere brightness ratio} = 1/(1-R_{\text{sphere}}*R_{\text{standard}})$$

The sphere brightness ratio in this case is the ratio of the luminance measured at the detector port with the reference sample covering the sample port divided by the luminance measured at the detector port with no sample covering the sample port. Knowing this brightness ratio and the reflectance of the calibrated standard ( $R_{\text{standard}}$ ), the reflective efficiency of the integrating sphere,  $R_{\text{sphere}}$ , can be calculated. This value is then used again in a similar equation to measure a sample's reflectance, in this case the PTFE light box:

$$\text{Sphere brightness ratio} = 1/(1-R_{\text{sphere}}*R_{\text{sample}})$$

Here the sphere brightness ratio is measured as the ratio of the luminance at the detector with the sample at the sample port divided by the luminance measured without the sample. Since  $R_{\text{sphere}}$  is known from above,  $R_{\text{sample}}$  can be calculated. These reflectances were calculated at 4 nm wavelength intervals and reported as averages over the 400-700 nm

wavelength range.

Relative gain (Effective Transmission (ET)) of crossed prism films can be measured with an assembly of two sheets of prism films, oriented one on top of the other, with the microstructured prisms facing away from the light source and toward the detector, and with the prism rows oriented approximately perpendicular to each other. At times, two measurements are taken, one with the pass axis of the polarizer in front of the detector oriented parallel to the top film prism rows in the film assembly, and one with the pass axis of the polarizer in front of the detector oriented perpendicular to the top film prism rows in the film assembly. The average of these two measurements is X-ETavg, and the minimum of these two measurements is X-ETmin.

When the relative gain of film assemblies containing a reflective polarizer is tested, the pass axis of the reflective polarizer was aligned with the pass axis of the absorbing polarizer of the test system. Relative gain values reported for prismatic films were generally obtained with the prism grooves of the film nearest the absorbing polarizer being aligned perpendicular to the pass axis of the absorbing polarizer.

% Increase in X-ETavg is determined by subtracting the X-ETavg of the control lacking the low refractive index coating from the same film having the coating, dividing the difference by the X-ETavg of the control, and multiplying by 100%. Likewise, % Increase in X-ETmin is determined by subtracting the X-ETmin of the control lacking the low refractive index coating from the same film having the coating, dividing the difference by the X-ETmin of the control, and multiplying by 100%.

### **Materials used in the Examples**

FPO 3740 is a fluoroelastomer terpolymer available from 3M Dyneon, St. Paul, MN. It has a refractive index of 1.356, measured at a wavelength of 633 nm.

Cellulose acetate butyrate (17% butyryl, ASTM viscosity 15) from Eastman Kodak used herein is similar to CAB-171-15, available from Eastman Chemical Company, Kingsport, Tennessee.

M1142 is 2-phenylphenoxyethyl acrylate available from Miwon Specialty Chemical

Co.Ltd. (Korea) under the trade designation "M1142".

SR602 is a bisphenol-A ethoxylated diacrylate monomer with an average of 5 ethoxylation repeats per acrylate, commercially available from Sartomer under the trade designation "SR602".

SR601 is a bisphenol-A ethoxylated diacrylate monomer with an average of 2 ethoxylation repeats per acrylate, commercially available from Sartomer under the trade designation "SR601".

HEAS is the reaction product of 2-hydroxyethyl acrylate and succinic anhydride prepared according to Example 1 of US Pat. App. Pub. No. 2011/0227008.

DCLA-SA is the reaction product of hydroxy-polycaprolactone acrylate and succinic anhydride prepared according to Example 1 of US Pat. App. Pub. No. 2011/0227008.

DAROCUR 4265 is a 50:50 blend of 2-hydroxy-2-methyl-1-phenyl-1-propanone and 2,4,6-trimethylbenzoyldiphenylphosphine oxide, available from Ciba Specialty Chemicals, Tarrytown, NY.

#### Polymerizable Composition 1

Polymerizable Composition 1 was 60 wt.-% SR602, 40% wt.-% M1142, and 0.5% Darocur 4265. Polymerizable Composition 1 had a refractive index of about 1.54 and the polymerized microstructured surface layer made from it had a refractive index of about 1.56.

#### Polymerizable Composition 2

Polymerizable Composition 2 was prepared like Composition 1 of US 2014/0058038, and contained 46.3 parts nano-zirconia, 10.8 parts HEAS, 2.5 parts DCLA-SA, 12.2 parts phenoxy ethyl acrylate, 8.1 parts SR601, 20.3 parts 2-phenyl-phenyl acrylate. The

refractive index of the uncured polymerizable composition is 1.626. The polymerized microstructured surface layer made from this has a refractive index of about 1.65.

#### Examples 1-1 through 1-11

Brightness enhancing film samples 1-1 through 1-11 were made using Polymerizable Composition 1 (polymerized refractive index of 1.56). About 3 grams of the warm polymerizable composition was applied to a 3 mil primed PET (polyester) film and placed against a microstructured tool with a 90/24 pattern, i.e. a prism apex angle of about 90 degrees and a spacing between prism peaks of about 24 microns. The PET, polymerizable composition and tool were passed through a heated laminator set at approximately 150°F to create a uniformly thick sample. The tool containing the film and coated polymerizable composition was passed at 50 fpm through a Fusion UV processor containing two 600 W/10 in D-bulbs to cure the film. The PET and cured polymerizable composition were removed from the tool.

Ten formulations for low refractive index coatings were made by dissolving 3M Dyneon Fluoroelastomer FPO 3740 (refractive index of 1.356) in MEK, at 1 wt-% increments, from 1% to 10% solids. The wt-% of the fluoroelastomer solutions was adjusted to provide the dry coating thicknesses indicated in Table 1.

The 10 low refractive index formulations were coated with a #3 Meyer Rod, and dried in an oven for 2 minutes at 140°F, onto the PET film surface (i.e. opposite surface as the polymerized microstructured surface layer comprising a plurality of prisms) of Brightness Enhancing Film Examples 1-2 through 1-11. Example 1-1 was left uncoated. The thickness was calculated from the Meyer Rod size, the solution % solids, the solution and coating density, and an empirical factor, and should be within 30%.

The percent change in X-ETavg brightness and X-ETavg min brightness is reported in Table 1. The maximum increase in X-ETavg brightness of the assembly of two prism sheets of Brightness Enhancing Film Examples 1-2 through 1-11 having the low refractive index coating was about 2.6%. Surprisingly, at least a 2% increase in X-ETavg or X-ETmin occurred at a coating weight between 135 and 236 nm. The maximum increase in

X-ETavg and X-ETmin occurred at a coating weight between about 170 and 200 nm.

**Table 1 – Polymerizable Composition 1 with and without Fluoropolymer Coating**

Example	Thickness* nm	% Increase in X-ETavg	% Increase in X-ETmin
1-1	0	Control	Control
1-2	34	-0.1%	0.2%
1-3	68	0.5%	0.7%
1-4	101	0.7%	0.9%
1-5	135	2.0%	2.3%
1-6	169	2.4%	2.7%
1-7	203	2.6%	2.9%
1-8	236	1.7%	1.9%
1-9	270	1.3%	1.4%
1-10	304	0.2%	0.3%
1-11	338	1.0%	1.2%

5

Examples 2-1 through 2-11

Brightness enhancing film Examples 2-1 through 2-11 were made with the same substrate, microstructured pattern, and opposite side coatings as Examples 1-1 through 1-11, except Polymerizable Composition 2 (polymerized refractive index of 1.65) was used for the polymerized microstructured surface layer.

10

The percent change in X-ETavg brightness and X-ETavg min brightness is reported in Table 2. Surprisingly, a 2% to 4% increase in X-ETavg occurred at a coating weight between 135 and 338 nm. Furthermore, a 4% to 7% increase in X-ETavg occurred at a coating weight between 101 and 338 nm. The maximum increase in X-ETavg and X-ETmin occurred at a coating weight between about 169 and 270 nm.

15

**Table 2 - Polymerizable Composition 2 with and without Fluoropolymer Coating**

Example	Thickness* nm	% Increase in X-ETavg	% Increase in X-ETmin
2-1	0	Control	Control
2-2	34	-0.1%	0.5%
2-3	68	0.5%	1.4%
2-4	101	1.0%	2.5%
2-5	135	2.4%	4.7%
2-6	169	3.7%	6.6%
2-7	203	4.1%	7.4%
2-8	236	3.8%	6.9%
2-9	270	3.2%	5.7%
2-10	304	2.5%	4.9%
2-11	338	1.8%	3.8%

5

Example 3

Brightness Enhancing Films 3 were made with the same substrate and microstructured pattern as Brightness Enhancing Film Examples 2-1 through 2-11 except that for the opposite side coatings, the ten formulations for low refractive index coatings were made by dissolving cellulose acetate butyrate in MEK, at 1 wt-% increments, from 1% to 10% solids. Cellulose acetate butyrate has a refractive index of 1.475. The maximum increase in X-ETavg brightness was about 2.6%. The maximum increase occurred at a low refractive index layer thickness between 100 and 130 nm, and again above 300 nm.

15

**Table 3 – Polymerizable 2 with and without Cellulose Acetate Butyrate Coating**

Example	Thickness* nm	% Increase in X-ETavg	% Increase in X-ETmin
3-1	0	Control	Control
3-2	34	0.4%	0.2%
3-3	68	1.2%	1.9%
3-4	101	2.7%	3.2%
3-5	135	2.5%	3.6%
3-6	169	1.5%	1.5%
3-7	203	0.0%	0.0%
3-8	236	1.4%	1.2%
3-9	270	1.9%	2.8%
3-10	304	1.8%	1.2%
3-11	338	2.6%	3.4%

**What Is Claimed Is:**

1. A microstructured optical film comprising a base film substrate having two major surfaces, a polymerized microstructured surface layer comprising a plurality of prisms  
5 disposed on one major surface of the base film substrate and a low refractive index layer disposed on the opposing surface of the base substrate, wherein the polymerized microstructured surface layer has a refractive index of at least **1.55** the low refractive index layer comprises a fluorinated polymer.
- 10 2. The microstructured optical film of claim 1 wherein the polymerized microstructured surface layer has a refractive index of at least 1.56, 1.57, 1.58, 1.59, 1.60, 1.61.
3. The microstructured optical film of claims 1-2 wherein the low refractive index layer has a thickness ranging from 50 nm to 1000 nm.
- 15 4. The microstructured optical film of claim 3 wherein the low refractive index layer has a thickness of at least 120, 125, or 130 nm.
5. The microstructured optical film of claims 1-4 wherein the polymerized  
20 microstructured surface comprises a polymerized organic component and inorganic oxide nanoparticles having a refractive index of at least 1.68.
6. The microstructured optical film of claim 5 wherein the inorganic oxide nanoparticles comprise zirconia.
- 25 7. The microstructured optical film of claims 5-6 wherein the polymerized organic component comprises a multifunctional (meth)acrylate monomer or oligomer.
8. The microstructured optical film of claim 7 wherein the multifunctional (meth)acrylate  
30 monomer or oligomer comprises an aromatic moiety.
9. The microstructured optical film of claims 7-8 wherein the polymerized organic

component comprises a monofunctional aromatic (meth)acrylate diluent.

10. The microstructured optical film of claims 1-9 wherein the low refractive index layer comprises a fluoropolymer comprising polymerized units of tetrafluoroethylene,  
5 vinylidene fluoride.

11. The microstructured optical film of claim 10 wherein the fluoropolymer further comprises polymerized units of hexafluoropropylene.

10 12. The microstructured optical film of claims 1-11 wherein the base film substrate has a thickness of ranging from 1 to 10 mils.

13. The microstructured optical film of claims 1-12 wherein the base film substrate has a refractive index of less than the polymerized microstructured surface layer.

15 14. The microstructured optical film of claims 1-12 wherein the low refractive index layer is in direct contact with the base film substrate.

15 15. The microstructured optical film of claims 1-14 wherein a primer layer having a  
20 thickness of less than 0.5 microns is disposed between the low refractive index layer and base film substrate.

16. A microstructured optical film comprising a base substrate having two major surfaces, a polymerized microstructured surface layer comprising a plurality of prisms and a low  
25 refractive index layer disposed on the opposing surface of the base substrate wherein the polymerized microstructured surface layer has a refractive index of at least 1.61 and the low refractive index layer has a refractive index that is least 0.10 less than the refractive index of the base film substrate.

30 17. The microstructured optical film of claim 16 further characterized by any one or combination of claims 1-15.



18. The microstructured optical film of the previous claims wherein the low refractive index layer further comprises a removable release liner.

19. An assembly of microstructured optical films comprising a first microstructured optical film proximate a base film substrate of a second microstructured optical film such that the prisms of the first microstructured optical film are aligned substantially orthogonal to the prisms of the second microstructured optical film; wherein the first and second microstructured optical film are according to claims 1-18.

20. The assembly of microstructured optical films of claim 19 wherein the low refractive index layer increases the brightness gain by at least 1.5, 2, 2.5, 3.0, 3.5, or 4%.

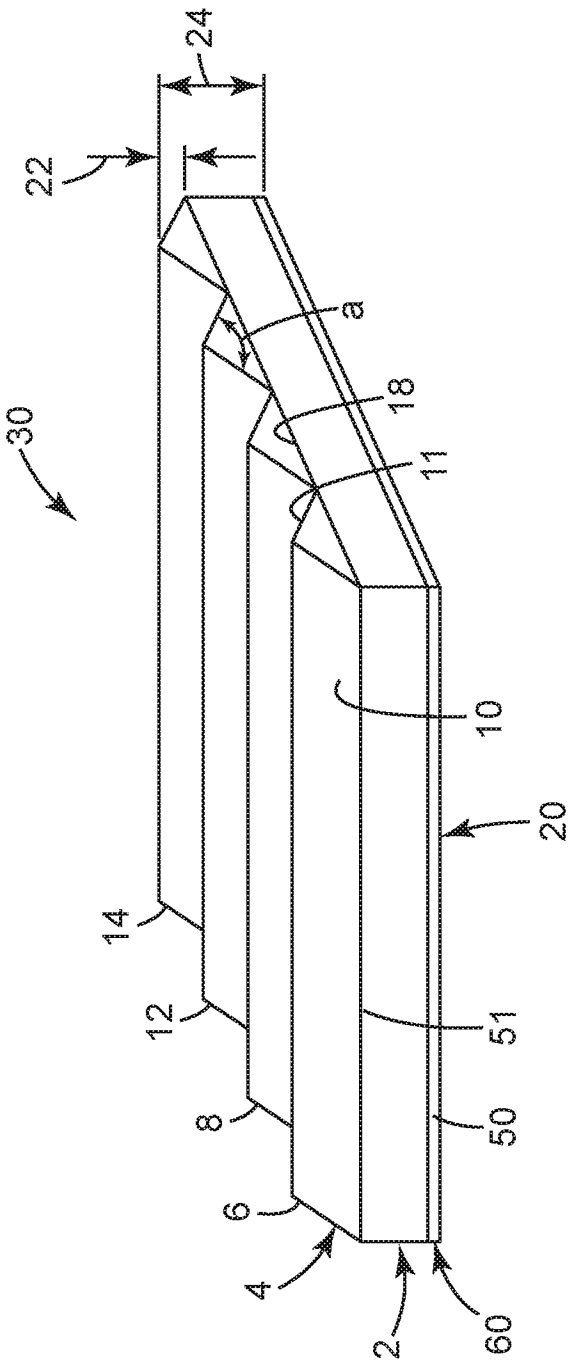


FIG. 1

## INTERNATIONAL SEARCH REPORT

International application No

PCT/US2016/020448

## A. CLASSIFICATION OF SUBJECT MATTER

INV. G02B1/11 G02B5/02 F21V8/00  
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

G02B B82Y

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)

EPO-Internal

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2007/285778 A1 (WALKER CHRISTOPHER B [US] ET AL) 13 December 2007 (2007-12-13)	1-12,
Y	paragraphs [0026], [0053], [0010], [0014], [0025], [0098], [0058], [0051], [0096], [0039]	16-20 13-15
Y	US 2007/286992 A1 (COGGIO WILLIAM D [US] ET AL) 13 December 2007 (2007-12-13) paragraphs [0119], [0123]	14,15
Y	US 2010/003501 A1 (LIU LAN H [US] ET AL) 7 January 2010 (2010-01-07) the whole document	13
Y	US 2006/204745 A1 (JONES CLINT L [US] ET AL) 14 September 2006 (2006-09-14) paragraph [0164]	13



Further documents are listed in the continuation of Box C.



See patent family annex.

## \* Special categories of cited documents :

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"&amp;" document member of the same patent family

Date of the actual completion of the international search

6 May 2016

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# INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2016/020448

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