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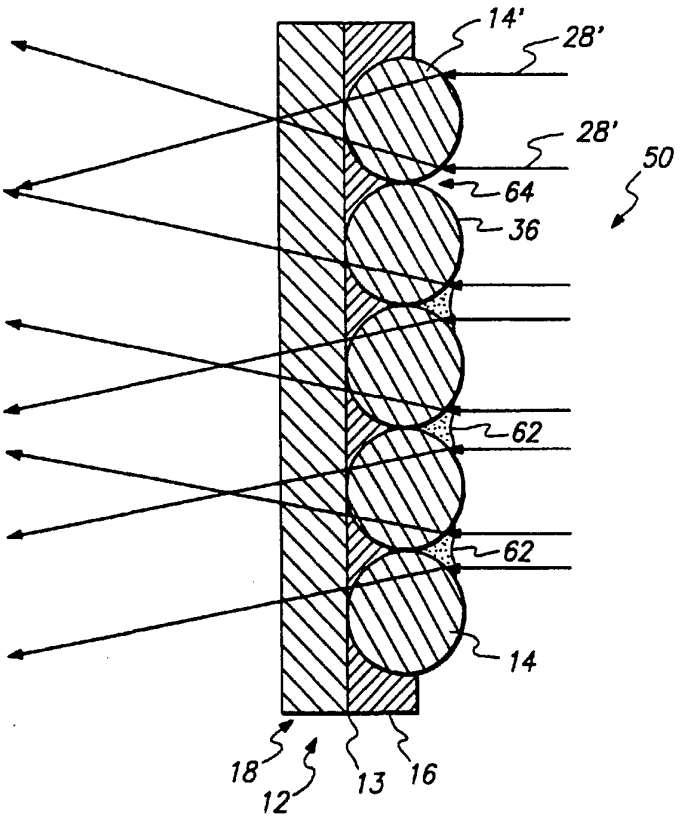
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(54) Title: A LIGHT TRANSMITTING AND DISPERSING PROJECTION SCREEN HAVING LOW REFLECTANCE

(57) Abstract

Multilayer light filters provide optimized gain control, contrast, and ambient light rejection through the addition of optical layers to a basic refraction light filter. These additional layers allow adjustment of the gain, contrast, and ambient light rejection of light filters in a substantially independent manner, and can be combined to simultaneously optimize these optical properties.



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A LIGHT TRANSMITTING AND DISPERSING PROJECTION SCREEN HAVING LOW REFLECTANCE.

Field of the Invention

This invention relates to the field of light filters, and in particular to light filters for rear projection screens, display enhancement, and other optical uses requiring dispersive light control.

Background of the Invention

Rear projection screens and light diffusers are light filters which provide an optically diffusing medium for transmitting light from an image source on one side of the screen to a viewer on the opposite side of the screen. A basic refractive light filter has been described in U.S. Patent No. 2,378,252, which includes a refracting lens system as its principal component. The refracting lens system comprises an array of spherical glass or resin beads embedded in an opaque binder layer and mounted on a transparent support material. Typically, the light filter is oriented with the bead layer towards the image source and the transparent support material towards the viewers. U.S. Patent No. 3,552,822 discloses a similar light filter which also includes an anti-reflection coating and has its bead layer oriented away from the image source.

The opaque binder layer serves a number of purposes, including affixing beads to the support material, reducing

the reflectivity of the filter, and reducing the amount of light transmitted through the interstices between the beads of the lens system. Light from an image is refracted by the beads and dispersed to the viewer through a transmission area of the beads. This transmission area comprises the point of contact between the bead and support material and the area surrounding this point where the binder layer is too thin to absorb the refracted light.

Rear projection screens and light diffusers are characterized by their ambient light rejection, resolution, gain, and contrast, properties which are determined by the structure and composition of the component materials. For example, the gain which is a measure of the intensity of transmitted light as a function of the viewing angle, is determined by the index of refraction of the spherical beads and the surrounding medium. Similarly, the ambient light rejection and contrast of the light filter are determined largely by the opacity of the binder layer. The resolution of the screen is determined by the size of the beads used in the lens system.

However, the interdependence of certain optical properties and their dependence on the properties of component materials, limit optimization of the optical properties of basic refractive light filters. For example, if the opacity of the binder layer is increased to enhance the ambient light rejection of the viewing surface, transmission of refracted image light through the binder layer in the transmission area of the bead will be reduced. In addition, the range of indices of refraction of available

materials also limits the performance of single layer filters. Such interdependencies and material limitations hamper the performance of basic refractive filters.

Summary of the Invention

The present invention is a multi-layer light filter that provides high image transmission, high ambient light rejection, high contrast, and improved gain control. Multi-layer light filters in accordance with the present invention include glass or resin beads supported in an opaque layer and modified by additional optical layers. These layers provide means to vary the optical properties of the filter, and consequently allow improved image transmission, ambient light rejection, and gain control.

In accordance with the present invention, the gain control provided by the index of refraction of the beads is augmented by the addition of a transparent resin layer to the rear surface of the beads. The transparent resin layer provides additional gain control by replacing the air/bead interface with air/resin and resin/bead interfaces at which the refraction of image light can be separately adjusted. Refraction at the resin/bead interface is controlled by selecting the relative indices of refraction of the transparent resin layer and the beads. Refraction at the air/resin interface may be adjusted by selecting the thickness of the transparent resin layer in addition to its index of refraction, a thin layer of transparent resin being effective to alter the shape of the rear surface of the beads.

Light reflection and absorption properties are improved by the addition of an opaque resin layer to the back of the

opaque binder layer, which allows the interstitial transmission of the multi-layer filter to be controlled without altering the opacity of the binder layer. Thus, the ambient light rejection, contrast, and control of interstitial transmission of the filter are enhanced without diminishing its image light transmission.

By combining transparent and opaque optical layers, the optical properties of multi-layer light filters in accordance with the present invention can be simultaneously improved.

Multi-layer light filters in accordance with the present invention may be used for example as rear projection screens or as contact light diffusers. In the first case, near-collimated light is incident on the light filter from an image light source which is well separated from the multi-layer filter. In the latter case, the multi-layer filter is positioned on an image source such as a flat panel display, which is illuminated from behind with collimated light.

Brief Description of the Drawings

Figs. 1A, 1B, 1C are schematic diagrams of a basic refractive rear projection screen, including cross sections taken at two different locations.

Fig. 2 is a diagram indicating the refraction of light rays by spherical beads in a basic refractive light filter.

Fig. 3 is a graph of the gain profiles for three light filters having different indices of refraction in the glass beads.

Fig. 4 is a schematic diagram of ambient light rays refracted and retro-reflected by the rear surface of beads.

Figs. 5A, 5B are schematic diagrams of light filters in accordance with the present invention in which the interstices between beads at the rear of the filters have been partially filled with transparent resin to control their gain.

Figs. 6A, 6B are schematic diagrams of light filters in accordance with the present invention in which a transparent resin layer having an index of refraction different from that of the spherical lenses has been added to the rear surfaces of the beads to control their gain.

Fig. 7 is a graph of the gain profile versus angle from the normal to the viewing surface for a basic refractive light filter and for a light filter having an additional resin layer in accordance with the present invention.

Fig. 8 is a cross section of a light filter in accordance with the present invention in which a second opaque layer has been added to the filter to enhance its ambient light rejection and image contrast.

Fig. 9 is a gain profile for a basic refractive light filter and for a multi-layer light filter including a second opaque layer.

Fig. 10A is a schematic diagram of a light filter in accordance with the present invention in which a second opaque layer and a transparent resin layer have been added to the filter to enhance its gain control, ambient light rejection, and image contrast.

Fig. 10B is a schematic diagram of a light filter in accordance with the present invention in which a second opaque layer and a thin transparent resin layer have been added to the filter to enhance its gain control, ambient light rejection, and image contrast.

Detailed Description of the Invention

Referring to Fig. 1A, there is shown diagram of a conventional, basic refractive light filter **10**. Referring to Figs. 1B and 1C, there are shown cross sections of light filter **10** at the locations indicated in Fig. 1A. Basic refractive light filter **10** includes a transparent support material **12** which has a filter surface **18** and a support surface **13**. Spherical glass or resin beads **14** are partially embedded in an opaque binder layer **16**, which binds beads **14** to support surface **13**.

Light from an image source is incident on filter **10** at back surfaces **36** of beads **14** and back surface **19** of opaque binder layer **16**, which define a back or image side of light filter **10**. Filter surface **18** defines a front side of light filter **10** through which viewers observer transmitted image light. Thus, light incident on beads **14** is refracted, transmitted through binder layer **16** at a transmission area **34**, and dispersed to viewers through filter surface **18**. Light incident on back surface **19** of binder layer **16** may reach viewers through interstices **20** between beads **14**. One role of opaque binder layer **16** is to reduce transmission of this light.

Referring now to Fig. 2, there is shown a diagram of the paths followed by refracted light rays **22-28** incident on back surface **36** of bead **14** at various distances from optic axis **30**. Light rays **22-28** are refracted towards optic axis **30** by an angle Ψ that increases with the distance between point of incidence **31** and optic axis **30**. Angle Ψ also

increases with the index of refraction of beads **14**. Refracted light rays **22-28** are directed through transmission area **34**, which includes the point of contact between bead **14** and support surface **13** as well as the surrounding area where intervening opaque binder layer **16** is too thin to absorb refracted light rays **22-28**. On the other hand, refracted ray **29** which strikes the front surface of bead **14** outside of transmission area **34** is absorbed as it transits opaque binder layer **16**.

Refracted rays **22-28** diverge after passing through transmission area **34** of bead **14**, dispersing transmitted light intensity over a range of angles Φ. In light filters **10**, the collective action of beads **14** disperses transmitted light intensity at various angles relative to a normal **11** of filter surface **18**, and this intensity distribution is referred to as the gain profile. High gain light filters **10** transmit image light in a narrow angular distribution about normal **11**, whereas low gain filters **10** transmit image light in broad distributions about normal **11**. The optimum gain for light filter **10** will depend on its intended use, and is selected in part by choosing component beads **14** having an appropriate index of refraction.

Referring to Fig. 3, there are plotted gain profiles **40, 42, 44** for basic refractive light filters **10** comprising beads **14** having indices of refraction of 1.5, 1.7, and 1.9, respectively. The gain at 0^{o} with respect to normal **11** is greatest for low index beads **14** and decreases with increasing index of refraction. The greater refractive power of high index beads **14** refracts transmitted rays **22-28**

more sharply than low index materials, and they subsequently diverge over a wider range of angles from normal **11** and are less focused along normal **11**.

In addition to gain, light filters **10** are characterized by their resolution, contrast, and ambient light rejection. It is generally desirable that filters **10** have both high resolution and high ambient light rejection. The resolution of light filters **10** is determined by the size of beads **14**, since the packing density of beads **14** on support surface **13** determines the density of transmission areas **34** on this surface. This property can generally be maximized by constructing filters **10** using the smallest diameter beads **14** available. The size of beads **14** selected may be dictated by variations in the quality and properties of available beads **14**.

Ambient light rejection measures how well ambient light incident on the front of a light filter **10** is absorbed or transmitted relative to the amount re-dispersed back to the viewer. This property depends primarily on the opacity of binder layer **16** and the index of refraction of beads **14**. Ambient light reflected into viewers' eyes from filter **10** can significantly impair the quality of an image by washing out the contrast.

In basic refractive filter **10**, ambient light incident on filter surface **18** may be reflected at the interfaces between: opaque binder layer **16** and support surface **13**, beads **14** and opaque binder layer **16**, and beads **14** and air at back surface **36**. Of these, the last is typically most important since the indices of refraction of support

material **12**, opaque binder layer **16**, and beads **14** can be made approximately equal, minimizing reflection from the first two interfaces.

It is not a simple matter to maximize ambient light rejection in basic refractive light filters **10** without compromising other optical properties, since the opacity of binder layer **16** affects these other properties. For example, increasing the opacity of binder layer **16** to improve ambient light rejection decreases the amount of image light transmitted through beads **14** in the zone around the point of contact between beads **14** and support material **12**, i.e. transmission areas **34**.

Specular, non-dispersive reflection from filter surface **18** is also present in all filters **10**, and is typically minimized by means of anti-reflection and anti-glare coatings and treatments. While these coatings and treatments are not within the scope of the present invention, they may be applied concurrently to enhance the overall performance of the present invention.

Referring now to Fig. 4 there are shown ambient light rays **23** passing through support material **12** and incident on rear surface **36** of a spherical bead **14** having an index of refraction of 1.5. Light rays **23** substantially parallel to optic axis **30** and incident on rear surface **36** of bead **14** at points **31, 33, 37**, undergo total internal reflection for points **31, 33, 37** more than approximately .7 R from optic axis **30**, where R is the radius of bead **14**. Thus, approximately 50% of the ambient light striking rear surface **36** of bead **14** will be retro-reflected. Retro-reflected rays

23 which are not absorbed by opaque binder layer 16 exit filter 10 along with transmitted image light 22-28, and thereby diminish the quality of the image.

In addition, image light transmitted through interstices 20 between beads 14 also reduces the quality of an image. Light rays 21 following this trajectory are not refracted by beads 14 and interfere with the gain profile of properly refracted light rays 22-28.

For basic refractive light filters 10, the intensity of light rays 21 transmitted through interstices 20 and those retro-reflected from beads 14 are controlled by the opacity of binder layer 16. Retro-reflected rays 23 pass through approximately twice as much binder layer 16 as transmitted rays 21, and are consequently absorbed at lower opacities than transmitted rays 21. However, increasing the opacity of binder layer 16 to reduce transmitted rays 21, reduces transmission of image light through transmission area 34 as discussed above. Thus, compromises between maximizing transmitted light and minimizing retro-reflected and interstitially transmitted light, limit optimization of basic refractive filters 10.

In addition to these limitations, the degree of gain control in basic refractive light filters 10 is also constrained. For instance, reducing the index of refraction of beads 14 to create higher gain at 0^{o} necessarily reduces the refracting power of beads 14. As a result, the amount of light focused into transmission area 34 and subsequently transmitted to filter surface 18 is reduced, reducing the intensity of transmitted image light. The degree of gain

control available through varying the index of refraction of beads **14** may also be limited by the physical properties of existing materials. Flattening beads **14** to increase the radius of curvature of the back surfaces **36** provides an alternative means for increasing the gain of basic refractive light filters **10**. However, where this flattening is achieved by simply compressing deformable resin beads **14** parallel to optic axis **30**, the distance between individual beads **14** increases, resulting in a lower density of beads **14** and lower resolution.

The present invention optimizes both the gain and ambient light rejection of light filters **10** through the addition of layers of material having selected optical properties and the substitution of new materials for the structures of light filters **10**. Thus, new light filters **50, 60, 70, 80, 90** as discussed in conjunction with Figs. 5, 6, 8 and 10 are produced by adding new layers **62, 72, 82** of optical materials to basic light filter **10**, which is constructed with glass or resin support materials **12**, binder layers **16**, and beads **14** selected to optimize the desired optical properties. Since filters **50, 60, 70, 80**, are based on light filter **10**, the components of light filter **10** and their combinations are discussed first.

With regard to material selection, the optical and mechanical properties of support material **12** contribute to the characteristics of filters 50, 60, 70, 80, 90in a variety of ways. For example, the index of refraction of support material **12** affects the angular distribution of transmitted light through refraction angles α, β, and the

contrast through its influence on internal reflection. In addition, absorbing materials can be included in support materials **12** to reduce back reflectance and lateral internal reflectance. For example, use of photochromic glass for support material **12** automatically increases the absorption and decreases the reflectance of support material **12** in bright ambient light conditions. Alternatively, the use of electrically active optical material for support material **12** allows the optical properties to be varied dynamically. These effects can be used in conjunction with the optical properties of beads **14**, binder layer **16**, and layers **62, 72, 82** to fine tune the performance of filters **50, 60, 70, 80**.

The mechanical properties of support material **12** can also be selected according to the use to which filters 50, 60, 70, 80, 90are put. For example, plastic support materials **12** reduce the weight and flexible materials such as plastic films can be used to produce flexible filters **50, 60, 70, 80**. By including a release agent on support surface **13**, support material **12** can be removed to provide flat or shaped free standing light filters **50, 60, 70, 80**.

Binder layers **16** may be made from a variety of matrix materials. For example, butyl methacrylate polymers readily mix with colorants and their thermoplastic properties provide a simple means for embedding beads **14**. Generally, UV, thermal, and chemically cured resins may be used to produce binder layer **16**. These materials may be applied in several layers **16** each having different optical densities. Alternatively, binder layer **16** may be a photosensitive film, in which case its optical density can be varied with depth

by exposure to actinic light. Photochromic materials on the other hand provide a binder layer **16** that automatically adjusts its absorption in response to ambient light conditions. In addition to film and resin type materials, binder layer **16** may be a wire mesh or perforated metal sheet as is discussed in conjunction with Fig. 5B, or a combination of mesh and clear resin materials.

For resin based binder layers **16**, beads **14** may be embedded in a close-packed array using a number of processes. In one method, support material **12** is coated with a thermoplastic resin binder layer **16** which is modified by a colorant to adjust the binder layer **16** to the desired opacity. Beads **14** are then spread over the thermoplastic resin binder layer **16** which is subsequently heated, allowing beads **14** to be pressed into resin binder layer **16** until they contact support surface **13**. Beads **14** may also be deposited by electrophoresis from a fluid medium, by spraying a mixture of beads **14**, material for binder layer **16**, and a solvent onto support material **12**, or by spraying beads **14** directly onto a softened binder layer **16**.

Close packing of beads **14** may be enhanced by applying electrostatic charges to beads **14** and/or binder layer **16** or support material **12** to position beads **14**. Alternatively, beads **14** may be pre-positioned on a surface shaped to enforce close packing, and subsequently transferred to binder layer **16**. Electrostatic assisted transfer as in xerography may also be used to transfer and position beads **14** onto binder layer **16**.

Beads **14** may be selected from a variety of glass or resin materials, the optimal material and size of beads **14** may depend on the intended application of light filter **50, 60, 80, 90**. Transparent glass or resin materials are available with indices of refraction of between about 1.4 and 2.1, and combinations of materials may be used to provide additional gain control. For example, beads **14** formed by encapsulating electro-optically active materials in glass or resin allow for the adjustment of the optical properties of beads **14** by application of an electric field. Beads **14** may also be composed of photochromic material to allow their optical properties to respond to changes in incident light intensity. Alternatively, colored beads **14** may be used to allow chromatic effects.

Light filters **50, 60, 80, 90** can be constructed with beads **14** of any diameter. In practice, the diameter is selected according to the desired resolution. However, beads **14** of differing diameter may be combined in the same light filter **50, 60, 80, 90**. For example, smaller diameter beads **14** may be added to the interstices **20** of an array of larger diameter beads **14** to increase the packing density. Beads **14** which can be permanently or temporarily deformed may also be used to provide an additional gain control mechanism.

Careful selection is necessary to eliminate out-of-round, wrong-sized, and discolored beads **14**. Out-of-round beads **14** cause uneven refraction of light, which creates bright spots and graininess in the viewed images in filters **50, 70, 80, 90**. The inclusion of opaque or frosted beads **14**

creates dark spots in filters **50, 70, 80, 90** and reduces transmission efficiency.

Preliminary sorting of beads **14** can be done using fine screens or meshes. Discolored beads are often ferromagnetic, and can be separated in a magnetic field. Out-of-round beads **14** can be separated by rolling them down a vibrating plane or allowing them to settle through a vibrating column, relying on the faster passage of round beads.

In certain instances, it may be useful to use beads **14** having non-spherical shapes such as ellipsoids or rounded rods. Such non-spherical beads can be deposited in alignments that provide different optical properties in different directions.

Once the basic light filter **10** has been generated in the manner described above, it is modified as described below to enhance the targeted optical properties. Referring now to Fig. 5A, there is shown a light filter **50** in accordance with the present invention, which provides additional gain control beyond that provided by the index of refraction of component beads **14**. Light filter **50** comprises a transparent support medium **12**, having a support surface **13** and a filter surface **18**, and an opaque binder layer **16** in which spherical beads **14** having a selected index of refraction are embedded. In addition, a thin layer **62** of transparent resin is deposited in depressions **64** created by back surfaces **36** of beads **14** protruding from back surface **19** of binder layer **16**. The index of refraction of resin layer **62** may be greater, less than, or substantially equal to

that of beads **14**, depending on the desired gain of filter **50**.

Resin layer **62** increases the effective radius of curvature of back surfaces **36** of beads **14**, thus reducing their refractive power. For comparison, refracted rays **28'** for untreated beads **14'** are shown at the top of Fig. 5A. The actual refractive power of beads **14** will vary with the degree to which depressions **64** are filled. This dependence provides a means to adjust the gain of light filter **50** in addition to changing the index of refraction of beads **14**.

As the depth of resin layer **62** in depressions **64** is increased, the effective radius of curvature of back surfaces **36** of beads **14** approaches infinity, i.e. a planar surface. In this limit, depressions **64** are completely filled with resin layer **62**, and as long as resin layer **62** has the same index of refraction as beads **14**, light rays incident normal to the resulting plane surface will not be refracted. Where resin layer **62** and beads **14** have different indices of refraction, however, refraction will occur at back surface **36** of beads **14**, providing another means for controlling the gain of multi-layer light filter **50** beyond varying the index of refraction of beads **14**.

Referring now to Fig. 5B, there is shown a light filter **50** in which opaque binder layer **16** is an opaque metal or plastic substrate **52** having a grid of perforations **54** in which beads **14** are supported. Perforations **54** are sized to accommodate beads **14** to a pre-selected depth **56**, and the grid of perforations **54** is chosen to provide close packing of beads **14** or alignment of beads **14** in a preferred manner.

The latter situation may arise for example where the source of image light is a digital video display, in which case it may be desirable to align beads **14** with the pixels of the video display.

As indicated in Fig. 5B, light filter **50** may be assembled with or without support material **12**. A flexible light filter **50** is provided by using a flexible opaque substrate **52** such as a plastic mesh or net, and either omitting support material **12** or using a flexible support material **12**. As noted above, a clear or colored resin layer may be combined with opaque substrate **52** to form binder layer **16**. A resin layer **62** may be included to increases the effective radius of curvature of rear surface **36** of beads **14**. In general, light filters **50, 70, 80, 90** realized using an opaque resin for binder layer **16** may also be implemented using opaque substrate **52** or a combination of resin and substrate **52** for the same purpose.

Where support material **12** is present, support surface **13**, bead **14**, and substrate **52** create a cavity **53** which may be filled with liquid or gases having optical properties chosen to alter the characteristics of filter **50**. Liquid or gas materials in cavities **53** extend the range of optical properties beyond what is available in solid materials. These properties can be altered by temperature, pressure, or radiation, adding another parameter to control the optical properties of filter **50**.

Referring now to Fig. 6A, there is shown a light filter **70** having gain control in addition to that provided by the index of refraction of beads **14**. Light filter **70** has an

array of beads **14** embedded in an opaque binder layer **16** which is affixed to support material **12**. In addition, a layer of clear resin **72** having an index of refraction different from that of beads **14** is added to rear surface **36** of beads **14** and rear surface **19** of binder layer **16**. Unlike layer **62** of light filters **50**, however, resin layer **72** is sufficiently thick to fully enclose beads **14** and present a planar surface **74** to incident image light. As indicated, light rays **28** from an image source are incident normally on planar surface **74** where they undergo no refraction. However, at interface **35** between resin layer **72** and beads **14**, light rays **28** are refracted by an amount determined by the difference between indices of refraction of these media. Thus, refraction at interface **35** and consequently the gain of light filter **70** can be adjusted by varying the index of refraction of resin layer **72** as well as that of beads **14**.

Ray **28** is drawn for the case where beads **14**, binder layer **16**, and support material **12** have substantially equal indices of refraction. As noted earlier, independent adjustment of the indices of binder layer **16** and support material **12** provide additional control over the gain of filter **70**.

Referring to Fig. 6B, there is shown a light filter **70** in which opaque binder layer **16** is a perforated opaque substrate **52**. The remaining features of light filter **70** are identical to those shown in Fig. 6A.

Referring now to Fig. 7, there are shown gain profiles **76, 78** for basic refractive light filter **10** and for two-layer light filter **70**, respectively, where each comprises

beads **14** having indices of refraction of about 1.9. Transparent resin layer **72** of light filter **70** has an index of refraction that is approximately 1.5. Due to the weaker refraction at the interface **35** between rear surface **36** of beads **14** and resin layer **72**, light rays **22-28** are transmitted more nearly parallel to optic axis **30**, giving light filter **70** a higher gain (**78**) than light filter **10**. The gain control is comparable to that provided by thin resin layer **62** of light filter **60**. Thus, the additional layers **62, 72** provide more complete control of the gain of light filters **50, 70**, respectively, than is possible with basic refractive light filters **10**. This is due to the fact that the gain of light filters **60, 70** can be controlled by adjusting the effective radius of back surface **36** of beads **14**, the index of refraction of beads **14**, and indices of refraction of second layer materials **62, 72** in any desired combination. Further, this additional control is achieved without adversely affecting the other optical properties of light filters **60, 70**.

Multi-layer light filters in accordance with the present invention may also include optical layers which enhance the contrast and ambient light rejection provided by the opacity of binder layer **16**. Referring now to Fig. 8, there is shown a light filter **80** in accordance with the present invention. In addition to support material **12**, refracting beads **14**, and binder layer **16**, light filter **80** includes a second opaque layer **82** which is deposited on back surface **19** of binder layer **16**. The opacity of layer **82** is selected to reduce the transmission of light through

interstices **20** to an acceptable level. The opacity of binder layer **16** is independently selected to reduce reflected light **23** to acceptable levels, without reducing transmission of image light through area **34**. With the multi-layer structure of light filter **80**, transmission through area **34** is not affected by the greater opacity of layer **82**, so the opacity of layer **82** can be increased to the eliminate light transmission through interstices **20**.

One way to generate opaque layer **82** is to deposit carbon black or some other powdered pigment such as xerographic toner on binder layer **16** and heat light filter **80** until the toner has diffused into the thermoplastic binder layer **16**. This provides a thin layer **82** at back surface **19** of binder layer **16** having greater opacity than layer **16**, the opacity of layer **82** being selected to reduce transmission through interstices **20** to acceptable levels.

Referring now to Fig. 9, there are shown gain profiles **84, 86** for light filters **10, 80**, respectively, having binder layers **16** with identical opacities. However, light filter **80** has additional high opacity layer **82**, which is not present in light filter **10**. Profile **84** of light filter **10** exhibits higher total light intensities for all angles, particularly near 0^{o}. The greater light transmission of profile **84** relative to profile **86** indicates that significant amounts of interstitially transmitted light reaches filter surface **18** at the opacities typically selected for binder layer **16**. The peak in this difference at 0^{o} is consistent with the fact that light transmitted through interstices **20** is neither refracted nor dispersed, and consequently is

transmitted predominantly parallel to normal **11** of filter surface **18**. This forward peaking also indicates that light transmitted through interstices **20** will interfere most with images viewed at small angles from normal **11**. The elimination of interstitially transmitted light in profile **86** means that images generated using light filter **80** will have superior contrast.

It is further noted that high opacity layer **82** may be combined with transparent resin layer **62** or resin layer **72** of light filters **50** and **70**, respectively, to provide a light filter **90** having enhanced contrast, ambient light rejection, and gain control relative to basic refractive light filters **10**. Referring now to Fig. 10A, there is shown a multi-layer light filter **90** having both high contrast opaque layer **82** and gain controlling, transparent layer **72**. In fig. 10B, there is shown a multi-layer light filter **90** in which tranparent layer **72** has been replaced with thin transparent layer **62**.

Therefore, improved light filters are presented in accordance with the present invention, that use additional, optically active layers to provide improved control over the optical properties of the light filter. By adjusting the thickness and optical properties of these additional layers, high performance light filters **50, 70, 80, 90** can be produced in which gain control, ambient light rejection, and contrast are optimized.

What is claimed is:

1. A light filter comprising:

a light transmitting material having a viewing surface and a support surface;

a layer of light absorbing material having a selected thickness and being affixed to the support surface of the light transmitting material, for controlling the reflectivity and transmissivity of the light transmitting material;

a plurality of beads of optically transmitting material, having a selected shape and arranged in a single-layer array, the beads being supported in the layer of light absorbing material;

an optical layer deposited over the layer of light absorbing material and the plurality of beads, for modifying the light transmitting properties of the light filter.

2. A light filter according to claim 1, wherein the layer of light absorbing material is an opaque plastic or metal material having a grid of perforations in which the beads are affixed.

3. A light filter according to claim 1, wherein the layer of light absorbing material is a resin which is effective to bind the array of beads to the support surface of the light transmitting material.

4. A light filter according to claim 3, wherein the thickness of the layer of light absorbing material is selected to embed approximately half of the bead in the light absorbing material.

5. A light filter according to claim 4, wherein the optical layer is a light transmitting resin that is deposited on the beads and the light absorbing layer to a depth such that the beads are completely embedded in the light transmitting and light absorbing layers.

6. A light filter according to claim 5, wherein the index of refraction of the optical layer is selected to be greater than the index of refraction of the beads.

7. A light filter according to claim 5, wherein the index of refraction of the optical layer is selected to be less than the index of refraction of the refracting beads.

8. A light filter according to claim 7, wherein the beads have spherical shapes.

9. A light filter according to claim 8, wherein, the diameters of the spherical beads are substantially equal.

10. A light filter according to claim 7, wherein the beads have an elongated shape and are positioned in the light absorbing layer with their elongated dimensions substantially parallel to the support medium and aligned in

a selected direction, for providing different gains parallel and perpendicular to the selected direction.

11. A light filter according to claim 7, wherein the layer of light absorbing material comprises a resin including carbon black to produce a pre-selected level of light transmissivity.

12. A light filter according to claim 11, wherein the resin is selected from one of butyl methacrylate polymer and ultra-violet cured resin.

13. A light filter according to claim 4, wherein the optical layer is a light transmitting resin having an index of refraction substantially equal to that of the refracting beads and is deposited to form a thin coating over the light absorbing layer, for altering the gain of the light filter.

14. A light filter comprising:

a light transmitting material having a viewing surface and a support surface;

a first layer of light absorbing material having a selected thickness and being affixed to the support surface of the light transmitting material, for controlling the reflectivity and transmissivity of the light transmitting material;

a plurality of beads of optically transmitting material, arranged in a single-layer array, the beads

being supported in the first light absorbing material; and

a second layer of light absorbing material deposited on the first layer of light absorbing material, for modifying the light transmitting properties of the light filter

15. A light filter in accordance with claim 14, wherein the first layer of light absorbing material is effective to bind the array of beads to the support surface of the light transmitting material.

16. A light filter in accordance with claim 15, wherein the second layer of light absorbing material has a lower transmissivity than the first light absorbing layer.

17. A light filter in accordance with claim 16, wherein the first layer of light absorbing material comprises a thermoplastic resin including a powdered black colorant, and the second layer of light absorbing material comprises a thin layer of thermoplastic resin including a higher concentration of powdered black colorant than the first layer of thermoplastic resin.

18. A light filter in accordance with claim 17, wherein the first layer of light absorbing material comprises a thermoplastic resin including carbon black, and the second layer of light absorbing material is formed from the first layer by depositing a layer of powdered black colorant on

the first layer and heating the resin until an additional thin layer of powdered black colorant has diffused into the adjacent surface of the first layer of resin.

19. A light filter comprising:

a light transmitting material having a viewing surface and a support surface;

a layer of light absorbing material having a selected thickness and being affixed to the support surface of the light transmitting material, for controlling the reflectivity and transmissivity of the light transmitting material;

a plurality of beads of optically transmitting material, arranged in a single-layer array, the beads being supported in the layer of light absorbing material;

a second layer of light absorbing material deposited on the first layer of light absorbing material, for modifying the light transmitting properties of the light filter; and

a layer of light transmitting material deposited over the second layer of light absorbing material, for modifying the light transmitting properties of the light filter.

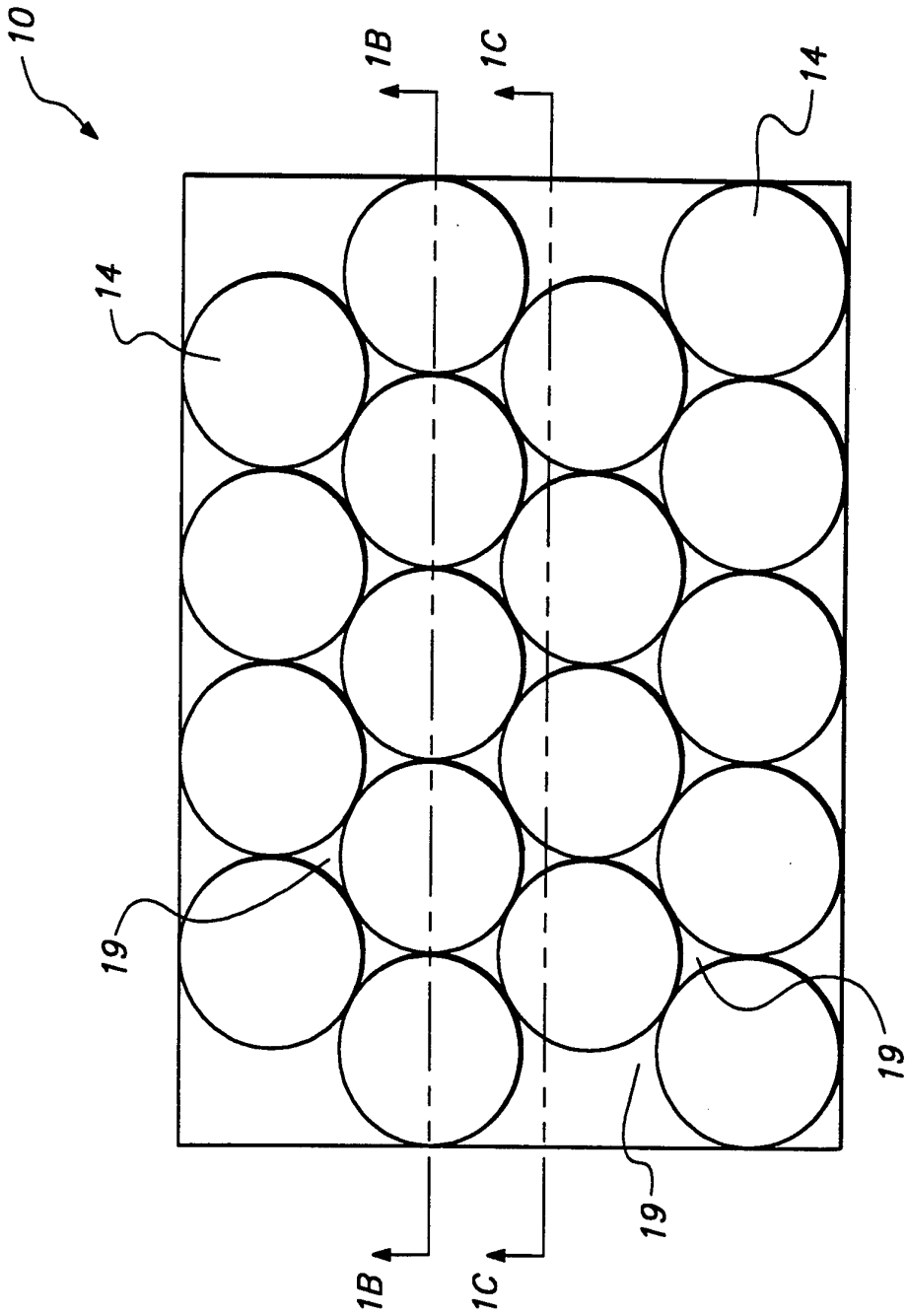


FIG. 1A (PRIOR ART)

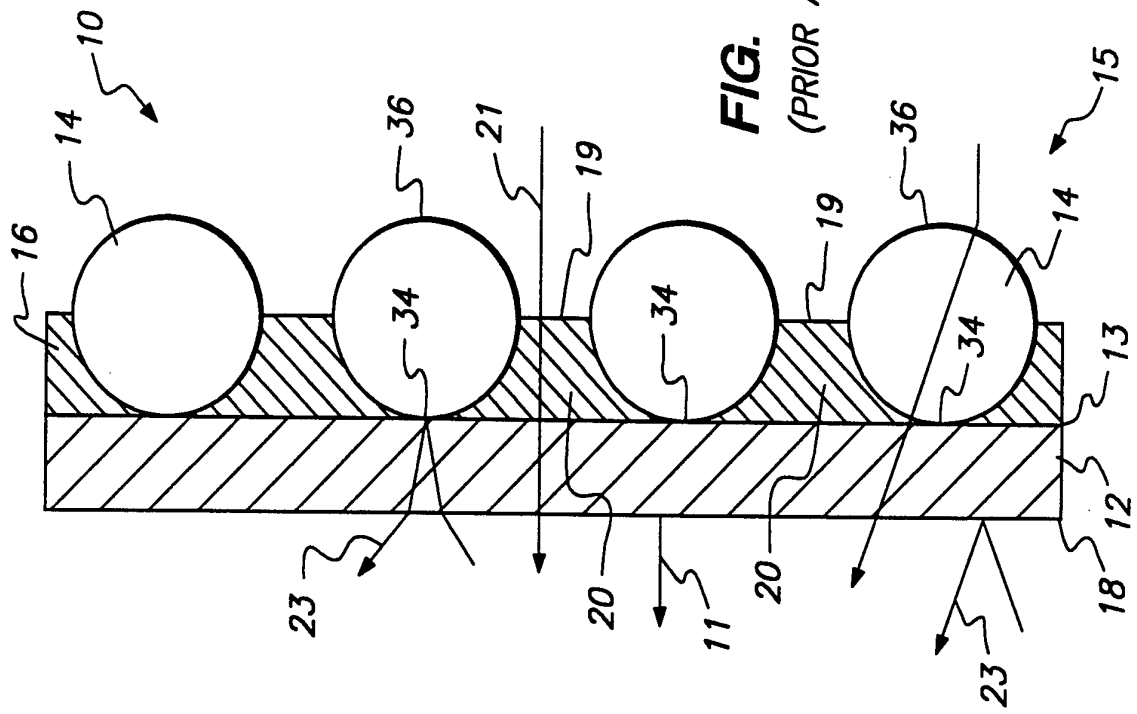


FIG. 1C (PRIOR ART)

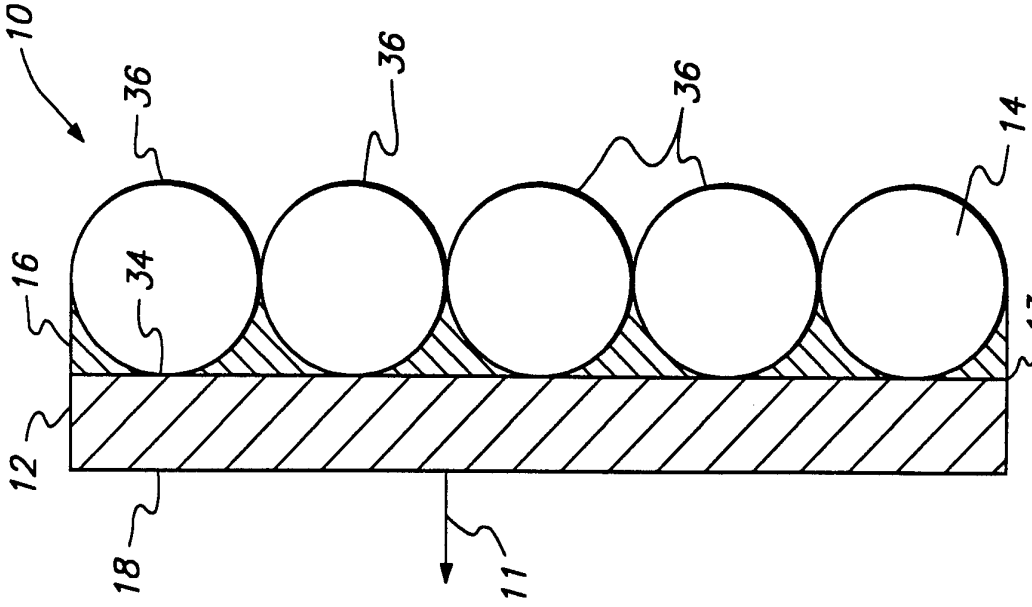


FIG. 1B (PRIOR ART)

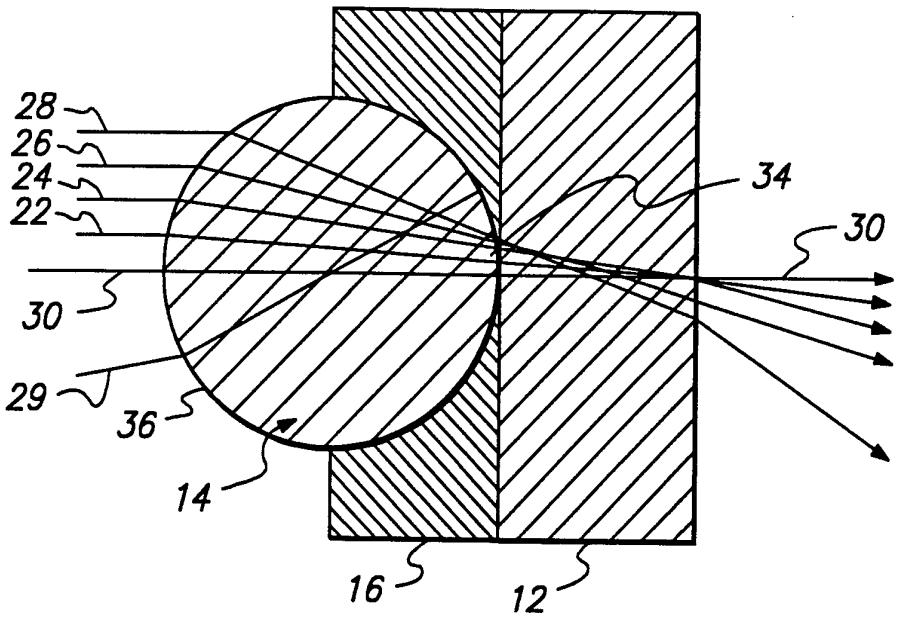


FIG. 2 (PRIOR ART)

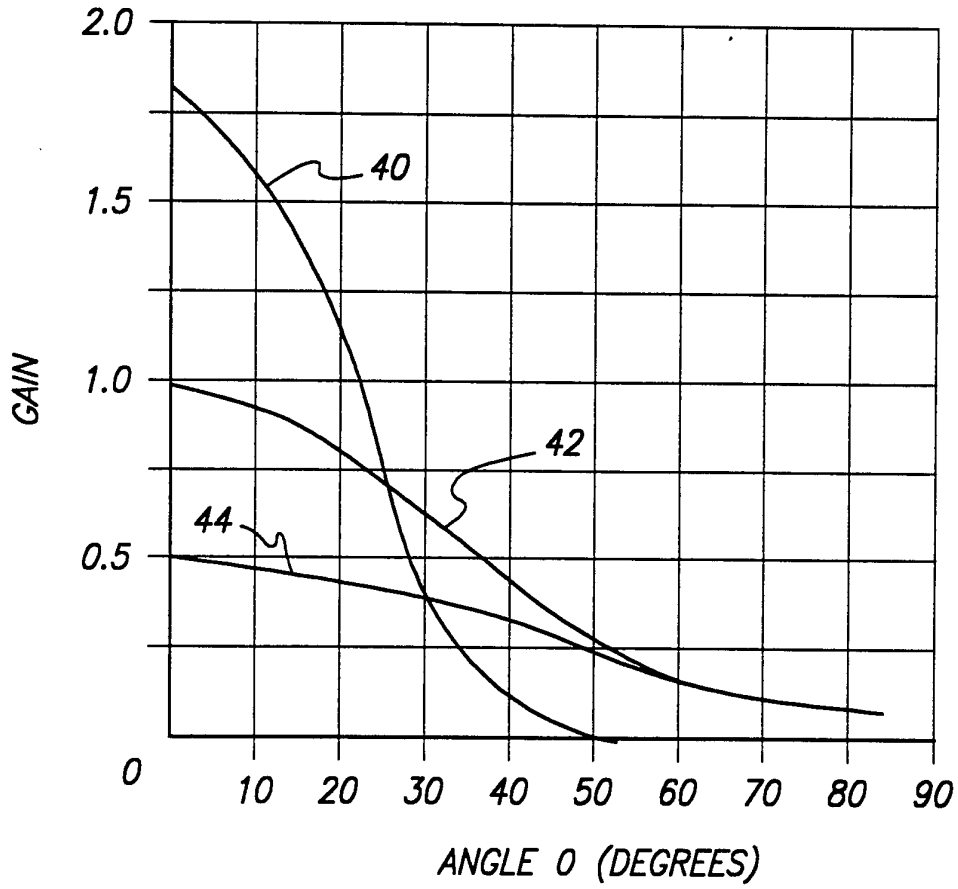


FIG. 3 (PRIOR ART)

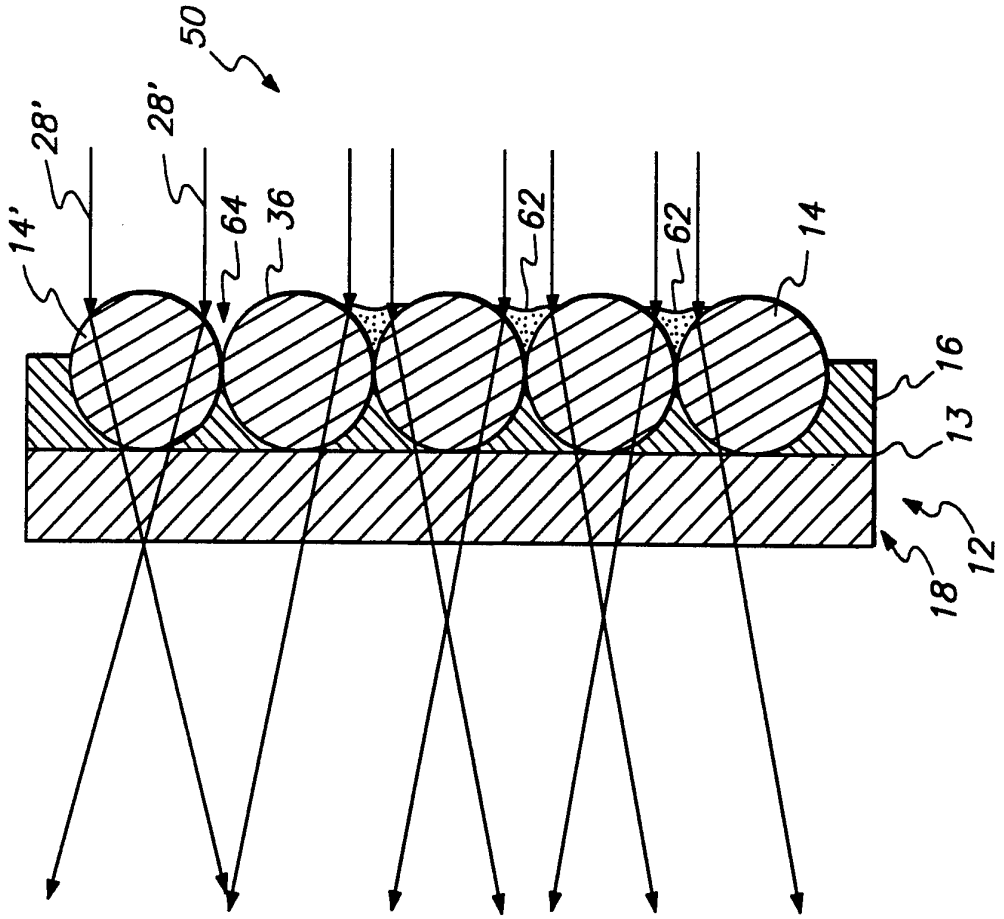


FIG. 5A

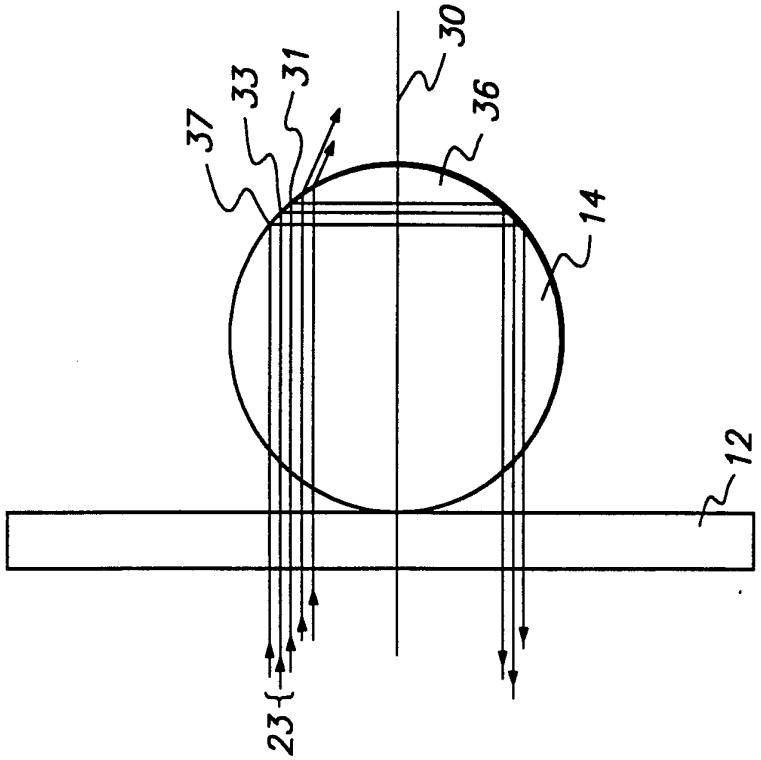


FIG. 4

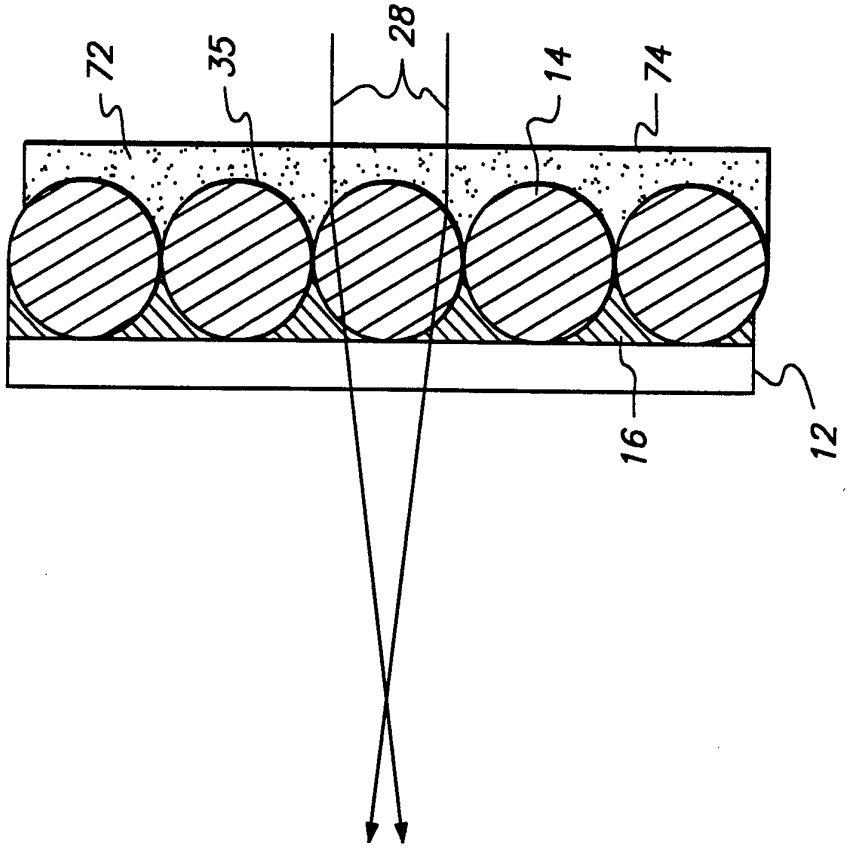


FIG. 6A

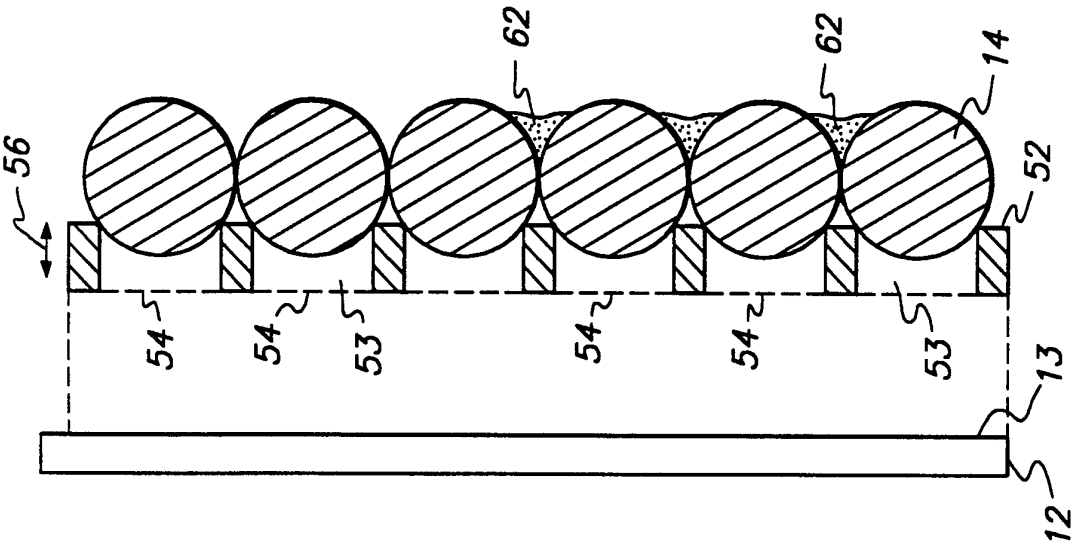


FIG. 5B

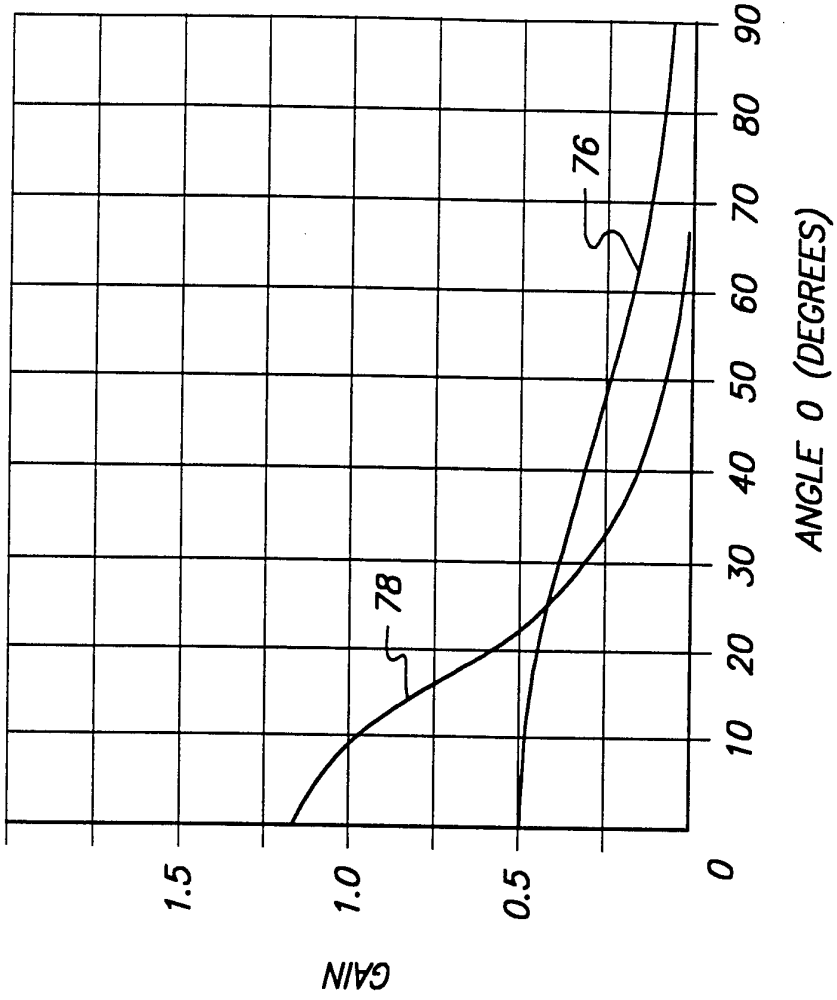

GAIN
1.5
1.0
0.5
0
10
20
30
40
50
60
70
80
90
ANGLE θ (DEGREES)
76
78

FIG. 7

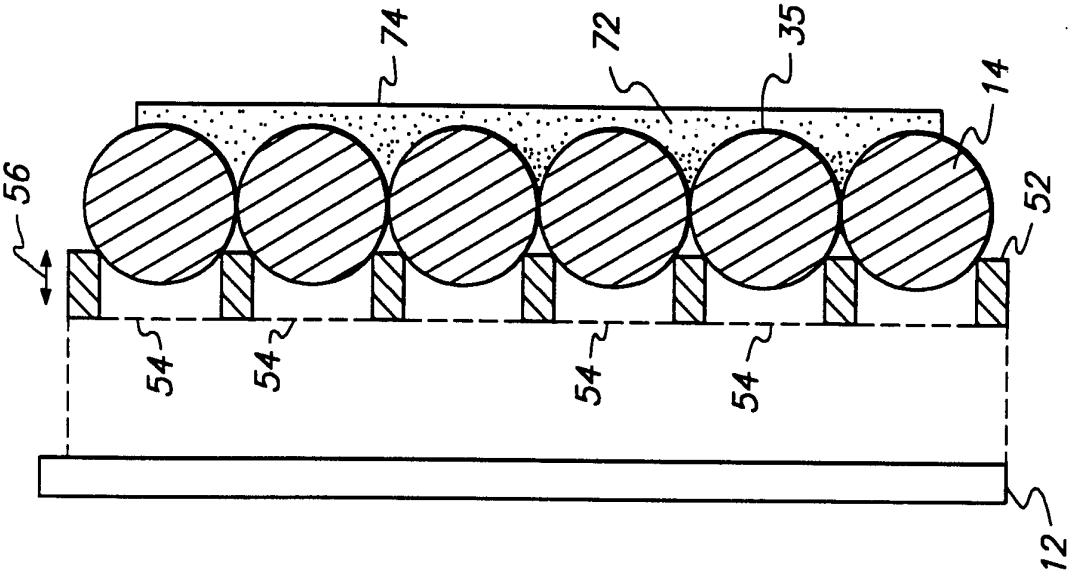

74
72
35
14
56
52
54
54
54
54
12

FIG. 6B

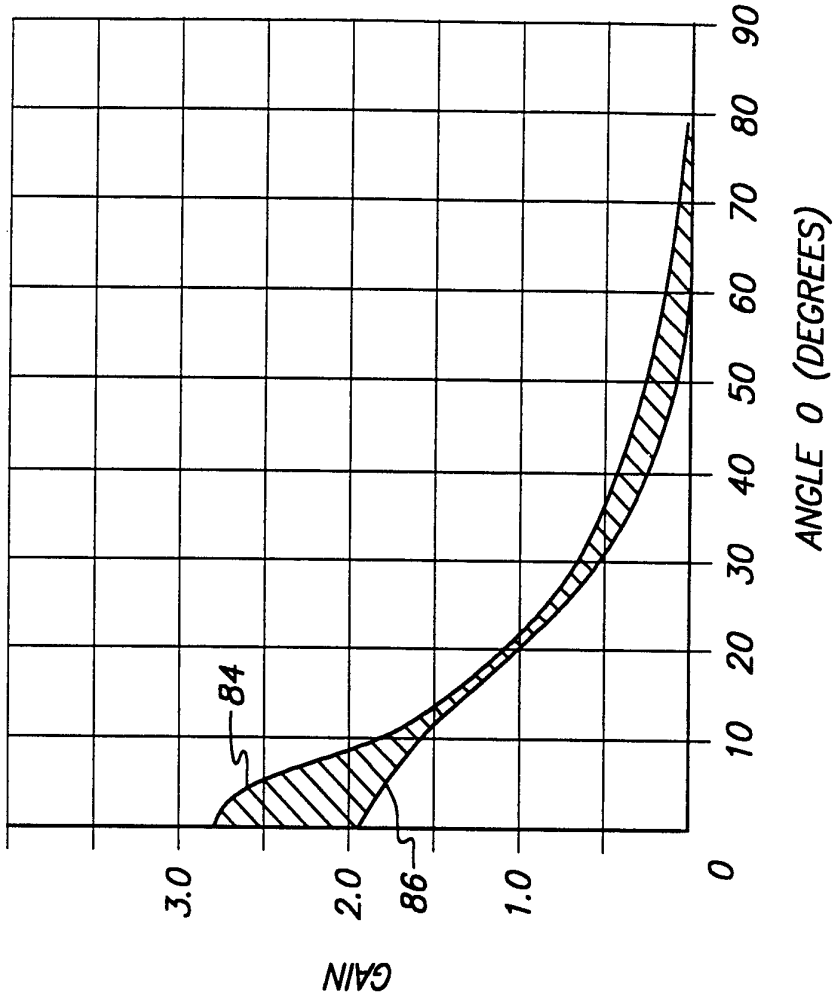

GAIN
3.0
2.0
1.0
0
86
84
10
20
30
40
50
60
70
80
90
ANGLE θ (DEGREES)

FIG. 9

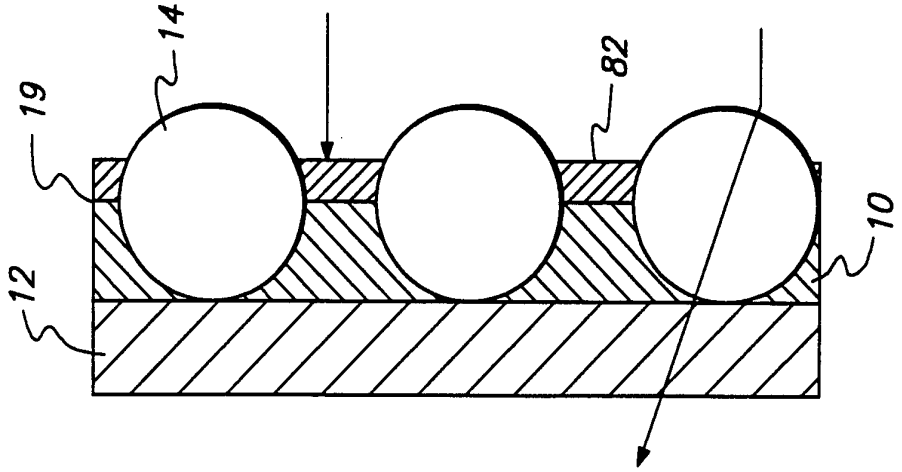

19
14
82
10
12

FIG. 8

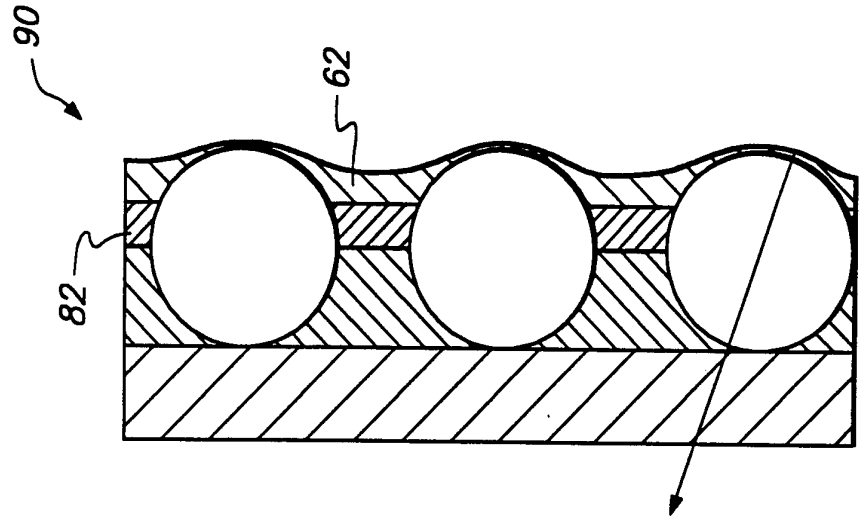


FIG. 10B

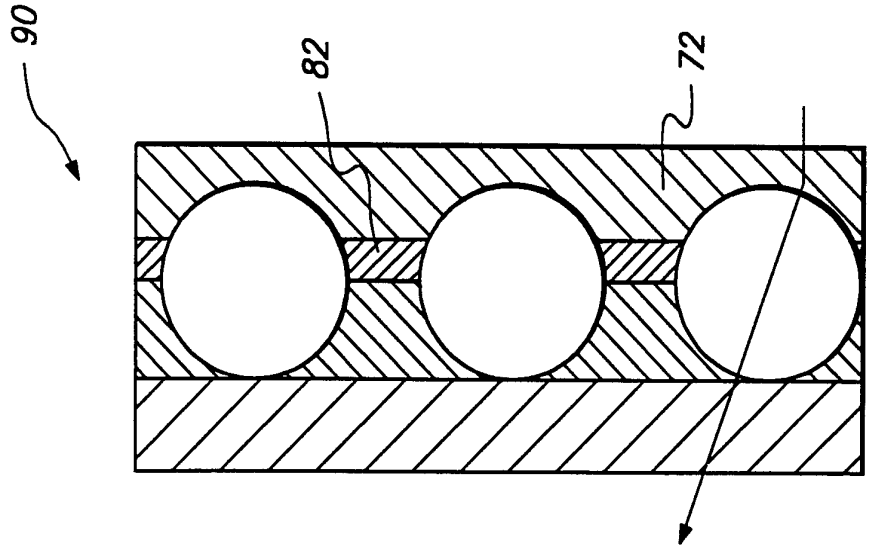


FIG. 10A