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(71) Applicant: ALLIEDSIGNAL INC. [US/US]; 101 Columbia Road, P.O. Box 2245, Morristown, NJ 07962-2245 (US).

(72) Inventors: SHACKLETTE, Lawrence, W.; 11 Alden Place, Maplewood, NJ 07040 (US). BEESON, Karl; 269 Christopher Drive, Princeton, NJ 08540 (US).

(74) Agents: CRISS, Roger, H. et al.; AlliedSignal Inc. Law Dept.(Amy Olinger), 101 Columbia Road, P.O. Box 2245, Morristown, NJ 07962-2245 (US).

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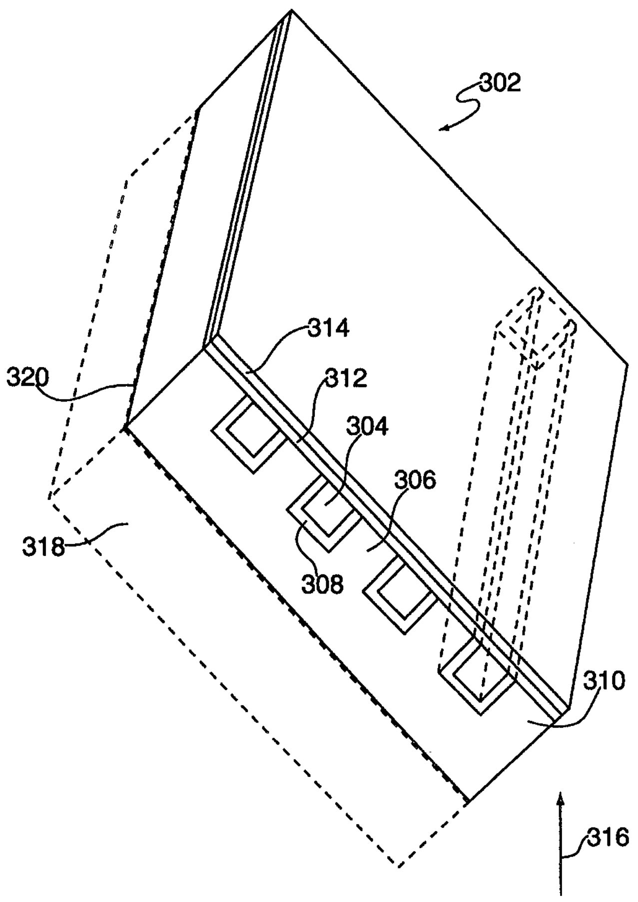
(54) Title: OPTICAL WAVEGUIDE HAVING NON ABSORBING CLADDING REGION

(57) Abstract

A waveguide having a core (304) and a cladding (306) that has light scattering particles and/or light absorbent particles distributed in said cladding. The cladding also has a halo region (308) around the core (304) that is depleted of the light absorbent particles. Due to the halo regions, the light scattering and/or light absorbent particles in the cladding can filter undesired light in the cladding without attenuating desired light propagating in the core of the waveguide such waveguides can be formed as an array. To enhance the filtering ability of the waveguide(s), the waveguide(s) can be bent out of a plane perpendicular to a planar face of the waveguide. Arrays of such waveguides are formed using, e.g., injection molding, compression-injection molding, extrusion, thermal embossing or soft embossing.



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OPTICAL WAVEGUIDE HAVING NON ABSORBING CLADDING REGION

FIELD OF THE INVENTION

This application claims the benefit of U.S. Provisional Application No. 60/077,345, filed March 9, 1998.

The invention is directed toward a waveguide having cladding that exhibits an unfilled skin effect, and more particularly to an array of such waveguides.

BACKGROUND OF THE INVENTION

In the art depicted in Fig. 1, it is known to scan an image on a document 102 using an array of waveguides 104 that spans the lateral dimension of the document 102. The output of the array of waveguides 104 is provided to a light detector 106, such as a charge coupled device (CCD). Electrical image data is output from the detector 106 to an image processor (not shown) via a data bus 108.

To scan a document, the array of waveguides 104 is moved across the document 102 in small increments and one row of image data is captured at each increment. The density of this image data and the optical performance of the array determine the maximum resolution of the captured image. This resolution can be expressed as a number of resolved pixels per inch (ppi) from the scanned page.

The array of waveguides 104 guides the image from the document 102 to the detector 106 and, for a flat-bed scanner, must allow a significant depth of field, e.g., greater than about 50% Modulation Transfer Function (MTF) for a given line pattern at a distance of four to five millimeters from the input of the array of waveguides 104 to the document 102. As used herein, MTF is typically measured for the captured image of an industry standard line pattern of equal width black and white bars with a periodicity denoted by the number of line pairs per inch (LPI). A typical line density for a 300 DPI scanner is 70 LPI, and for a 600 dots per inch (DPI) scanner is either 105 LPI or 140 LPI. The line pattern produces a modulation in the output of the detector with a greater signal corresponding to the image of a white bar (max) and a lesser signal corresponding to the image of a black bar (min). The modulation transfer function (MTF) is defined as MTF = (max - min)/ (max + min), and is expressed as a percentage.

For a 300 DPI scanner (lateral resolution of 300 ppi at the page), it is difficult to maintain the necessary light gathering power and still provide the required depth of field. For a resolution of 600 DPI or more, the difficulty increases significantly.

In order to have the required depth of field, the array of waveguides 104 should efficiently collect light rays that reflect nearly perpendicularly off the document 102 yet reject those light rays which impinge on the array 104 at more than a maximum angle of acceptance, relative to the axial direction 112 of the array 104. Light impinging at an angle less than or equal to the maximum acceptance angle can be considered to have reflected from a page pixel from the row of pixels immediately in front of the face of the array of the given waveguide 104.

Depending on the optical design of the waveguide array, the acceptance angle for light rays in the lateral (horizontal) plane which coincides with the plane of the array may be different from that for rays lying in a vertical plane which is perpendicular both to the plane of the scanned page and the plane of the array.

There is a required finite gap 110 between the face of the array of waveguides 104 and the document 102 to accommodate, e.g., a 3 mm glass platen (not shown) and a 1-2 mm clearance gap between the platen and the waveguides 104. This gap 110 permits light at angles greater than the designed acceptance angle, i.e., light from pixels above or below or to the left or right of the pixel immediately in front of the given waveguide in the array 104, to impinge on the face of that waveguide. For that particular waveguide, this light from neighboring page pixels is unwanted. The waveguide must have a numerical aperture and a shape (e.g., a taper) which will result in the angle of the unwanted light falling outside its acceptance angle.

For an array of waveguides 104 that is to be used with a 600 DPI scanner, the lateral projection of this predetermined maximum angle must be less than about 0.6°, and preferably less than 0.4°.

Light which impinges at an angle greater than the maximum acceptance angle must be rejected (as noise) from the optical signal carrying the image. Unfortunately, most of the light emanating from the scanned document 102 is noise that must be rejected. If a relatively small fraction of this light reaches the CCD 106, the signal-to-noise ratio of the analog electrical signal of the bus 108 will be significantly degraded.

Figure 2 is a three-quarter perspective view of the conventional array of waveguides 104. The array 104 has a plurality of clear cores 202 arranged in parallel in a clear cladding 204. Rejected (unwanted) light can either propagate within the cladding or, through scattering, stray from one waveguide to another before reaching the detector. This rejected light must be prevented from reaching the detector, where it would add to the noise background and degrade resolution and depth of field.

The angle of accepted light must be made narrower for a 600 DPI scanner as compared to the 300 DPI scanner. The array of waveguides in Fig. 1 has no provision for absorbing rejected light. It provides an optical signal to the detector 106 that has a signal-to-noise ratio that is much too small to be practical.

SUMMARY OF THE INVENTION

An advantage of the invention is that it provides a waveguide which can filter out light that has entered the waveguide at more than a maximum acceptance angle.

Another advantage of the invention is that it provides a technology for absorbing stray light so as to prevent it from propagating in the cladding surrounding the core of a waveguide.

Another advantage of the invention is that it provides an array of such waveguides, e.g., to be used as an optic for capturing an image of a scanned document. Such waveguides suffer a loss of less than 1dB/cm, preferably less than 0.5dB/cm, and most preferably < 0.2dB/cm for light within their acceptance angle.

Another advantage of the invention is that it provides a method for producing such a waveguide, and/or an array thereof, that is practical and inexpensive. To be practical and inexpensive, such a method preferably does not require an intermediate step involving registration, i.e., alignment, relative to the position(s) of the core(s) of the waveguide(s).

These and other advantages of the invention are achieved by providing a waveguide comprising a cladding layer and a core. Here, the cladding layer has light absorbent or light scattering particles distributed therein and a halo region located around the core. The halo region is depleted of said light absorbent particles.

These and other advantages of the invention are also achieved by providing a waveguide structure comprising: an array of waveguides, each of said waveguides having a cladding and a core. Here, the cladding has light scattering particles and/or light absorbent particles distributed therein and halo regions around each core. Each halo region is depleted of the light scattering and/or absorbent particles.

These and other advantages of the invention are also achieved by providing a method of forming an array of waveguides having cladding that exhibits an unfilled skin effect, the method comprising: a) forming a first cladding layer of cladding material having light absorbent or light scattering particles therein; b) forming grooves (channels) in the first cladding layer such that halo regions, depleted of the light absorbent or scattering particles, are formed in the first cladding layer around the grooves, respectively; c) forming cores in the grooves; and d) forming a second cladding layer on the first cladding layer and the core layer.

The step b) of forming the grooves in the first cladding layer is preferably carried out via injection-compression molding, or alternatively, via thermal or soft embossing.

The foregoing and other objectives of the present invention will become more apparent from the detailed description given hereinafter. However, it should be understood that the detailed description and specific examples, while indicating preferred embodiments of the invention, are given by way of illustration only, since various changes and modifications within the spirit and scope of the invention will become apparent to those skilled in the art from this detailed description.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention will become more fully understood from the detailed description given hereinbelow and the accompanying drawings which are given by way of illustration only, and thus are not limitative of the present invention and wherein:

Figure 1 is a drawing of a conventional scanning system employing a conventional waveguide array;

Figure 2 is a three-quarter perspective view of the conventional array of waveguides;

Figure 3 is a three-quarter perspective view of an array of waveguides according to the invention;

Figure 4 is a side view of the array of waveguides according to the invention bent so that the array of waveguides bends out of a plane normal to the planar face thereof;

Figure 5A-5E depict the steps in the method according to the invention for forming a waveguide, or array thereof, according to the invention;

Figure 6 depicts aspects of one of the embodiments of the method according to the invention;

Figure 7 depicts aspects of another one of the embodiments of the method according to the invention; and

Figure 8 is a cross-sectional view of the array formed via the embodiment of Figure 7.

DETAILED DESCRIPTION OF THE INVENTION

Figure 3 depicts a three-quarter perspective view of an array of waveguides according to the invention. The face 310 of the array 302 corresponds to a cross-sectional view of the array 302. The array 302 includes a plurality of parallel clear cores, each core preferably being square in cross-section and, e.g., having sides of about 3 μm to 1 mm in length. It is preferred for the invention to be used with cores or channels of widths less than 100 μm, and preferably less than 50 μm. A first cladding layer 306 is formed around the cores 304.

The first cladding layer 306 preferably contains light scattering particles and/or light absorbent particles. Examples of light absorbent particles include carbon black, graphite fibers, a black pigment or black-dyed polymer particles. The light absorbent particles cause the cladding layer 306 to have a blackened appearance. However, the first cladding layer 306 also has a halo region 308 around each core 304. The halo region 308 is substantially depleted of the light scattering particles and the light absorbent particles such that it is substantially clear.

The first cladding layer 306 is formed on a substrate 318. A thin adhesion promoting layer 320 promotes adhesion between the substrate 318 and the first cladding layer 306. The substrate 318 and the adhesion promoting layer 320 are preferred, but have been depicted with dashed lines because each is optional. For simplicity, the optional albeit preferred substrate 318 and adhesion promoting layer 320 have not been depicted in Figs. 4, 5A-5E and 7-8.

To achieve the desired halo effect, the light scattering and light absorbent particles are preferably larger than one micron, and more preferably larger than three microns, and even more preferably larger than ten microns. This size range contrasts with the optimal size for pigment particles, which is typically less than 1 micron, and is chosen to optimize the halo effect rather than the hiding power of the filler (pigment). The thickness of the halo region is preferably in the range of one to ten microns, and more preferably in the range of 3 to 6 microns.

Each halo region 308 surrounds three sides of a core 304. Against the fourth side of the core 304 and the corresponding surface of the first cladding layer 306 is formed a second, preferably clear, cladding layer 312. A light absorbing layer 314 is optionally, but preferably, formed against the second cladding layer 312. To simplify the drawing, internal details for only one of the cores 304 and halo regions 308 are shown with phantom lines.

Light can be eliminated from the cladding regions by absorption, scattering, or both. Enhancing the scattering of light within the cladding is particularly useful when one or more black (absorbing layers) are employed above or below the cladding layer. Scattering and absorption can be enhanced by the inclusion of a filler material or the use of a phase separated blend or co-polymer.

A domain of a polymer phase or a filler particle can be characterized by its index of refraction, n + ik. In general, the index of refraction is characterized by both real (n) and imaginary (k) parts. Absorption is based upon the imaginary part of the index. Scattering is based upon the magnitude of the index (both real and imaginary parts), which determines the difference between the index of the included particle (or domain) and the index of the surrounding matrix. Scattering of light occurs when the index of refraction of the inclusion is either higher or lower than that of the matrix, and the longest dimension of the particle or domain size is comparable to or larger than the wavelength of the light to be scattered. A general rule for nearly spherical particles is that scattering is maximized when the particle diameter is approximately one half of the wavelength of light to be scattered. Examples of dielectric materials which have a value of k near zero and, which are, therefore, capable of scattering light but not absorbing it, include many polymers and a variety of mineral fillers such as silica, alumina, titanium dioxide, zinc sulfide, zinc oxide, antimony oxide, barium sulfate, calcium carbonate and the like. Gas-filled voids are also useful for the practice of the invention.

Whether the included particle or domain is absorbing or not, it is, nevertheless, desirable to keep the particle or domain away from the interface between the core and cladding of a waveguide in order to prevent the loss of wanted light from said core of the waveguide. Absorbing particles in the vicinity of the waveguide will contribute to absorption of light from the core while dielectric (scattering) particles can cause scattering from the core by altering the local difference in index between core and cladding.

The halo regions 308 will now be discussed in more detail. As mentioned previously, there can be two kinds of light which propagate in each of the waveguides in the array 302. The first kind is the desired kind corresponding to light that impinges upon the cores 304 at the face 310 of the array 302 at less than or equal to the maximum angle of acceptance relative to the axial direction 316 of the array 302. The second kind of light is the undesired kind of light corresponding to light impinging at an angle greater than the maximum acceptable angle of acceptance, which has been chosen to provide the desired depth of field and MTF.

Light outside of the maximum angle of acceptance will not propagate within the guide without substantial loss. Such light will successively leak from the guide upon each encounter with the interface between core and cladding. Ultimately this light will reside within the cladding or within the regions outside the cladding.

For the desired kind of light to propagate in the waveguides of the array 302 without losing energy, for a step-index waveguide, such light must undergo total internal reflection (TIR) as it encounters the interface between core and cladding.

As known from the wave theory of light, at each TIR there is an evanescent wave that propagates parallel to the core, but extends laterally into the cladding surrounding the core over a characteristic distance known as the lateral penetration depth. The evanescent wave is linked to the wave propagating within the core.

The evanescent wave has a lateral penetration depth which varies as a function of the index of refraction of the core, the index of the refraction of the cladding, the wavelength of the light and the angle of incidence at the interface of the core and cladding. The power of the evanescent wave decreases exponentially in proportion to the distance from the core into the cladding.

If the evanescent wave in the cladding is attenuated by absorption, e.g., due to our encounter with an absorbent or a scattering particle, the intensity of the wave propagating in the core is correspondingly attenuated. It is desired for the wave in the core to propagate without being attenuated. Thus, it is desirable for the evanescent wave to propagate without attenuation. The lateral penetration depth of the evanescent wave ranges between nearly zero for glancing incidence waves and infinity for waves incident at the critical angle. However, as a practical matter, it is sufficient to provide a substantially clear, non-absorbing cladding for a distance of at least about three microns into the cladding as measured perpendicular to the core/cladding interface.

The effect of restricting the depth to which the evanescent wave can penetrate without loss is to decrease the acceptance angle of the waveguide. As long as the evanescent wave can penetrate to about 3 microns, the effect is small. Useful operation may still be obtained in certain cases where only 1 micron of non-absorbing cladding is provided. Below this limit of 1 micron, the waveguide becomes very lossy for all waves outside a very narrow range of acceptance angles and also becomes very intolerant of bends or tapers.

Similar concerns about evanescent wave propagation are manifested in conventional optical fibers, which have a clear core and a clear cladding. The cladding is formed to be thick enough so that dirt on the cladding does not attenuate propagation of the evanescent wave in the cladding. The use of light absorbent particles in the cladding according to the invention is analogous to the dirt on the outside of an optical fiber. However, instead of being a problem to prevent, the light absorbent particles are desired aspects of the invention, albeit under controlled circumstances, namely the non-uniform distribution of the light absorbent particles, which is characterized by the halo regions.

Again, it is not desirable for the entire first cladding layer 306 to be clear because of the presence of undesired light in the waveguide that impinges at an angle greater than the maximum angle of acceptance. Such light generally does not undergo

TIR in the waveguide. Rather, it is refracted out of a first waveguide into the cladding. To prevent the undesirable light in the cladding from propagating into an adjacent waveguide or reaching a detector at the output, it is beneficial to have the light absorbent particles (which correspond to undesired dirt in the conventional art) in the cladding, albeit outside the preferably clear halo region 308 surrounding each core 304.

Figure 4 depicts an alternative, and preferred, embodiment of the array 302. In Figure 4, the array 302 is shown as being bent rather than planar. In more detail, the array 302 bends out of a plane normal to the planar face 310 of the array 302. This out-of-plane bend promotes propagation of the unwanted light, namely light that enters the face 310 of the array 302 at an angle greater than the maximum angle of acceptance, into the cladding layers 306 and 312 where it is absorbed by the light absorbent particles and/or scattered by the light scattering particles in the layers 306 and 314.

The preferred radius and angular extent of the out-of-plane band depends on the numerical aperture (NA) of the waveguide, the length of the waveguide, and the height of the core of the waveguide. The preferred bend radius is that which will incur less than a loss of about 0.5 dB and more preferably less than about 0.1 dB. Bend radii will preferably lie in a range from about 0.2 cm to about 2 cm. The angular extent of the bend will preferably lie in the range from about 10° to about 90°.

As alluded to above, a method of creating the optical waveguide of the present invention comprises the use of transparent photocuring polymers on the substrate 318 (Fig. 3). The core 304 is surrounded by the cladding 306, which is supported by the substrate 318 that has been coated by the optional adhesion promoting layer 320 (Fig. 3). Depending on the application, waveguide core 304 is transparent to light preferably within the wavelength range from about 400 to about 1600 nm. Generally, single specific applications will require transparency over smaller defined wavelength ranges such as 400 to 700 nm, 800 to 900 nm, 1280 to 1350 nm, or 1520 to 1580 nm.

To aid in manufacture, it is preferred for the substrate 318 to transmit ultraviolet light in the range from about 250 to about 400 nm, as this is the range in which many useful photoinitiators absorb light. Although opaque materials can be used, the substrate 318 is preferably made from any transparent solid material. The index of refraction of the substrate 318 may range, e.g., from about 1.45 to about 1.65, but preferably from about 1.50 to about 1.60. The index of refraction of the substrate material is preferably chosen to be greater than that of the cladding 306, so that stray light which may be propagating within the cladding can escape to the substrate. In some instances the substrate may be dyed black or gray so as to further absorb stray light, or a black coating may be applied to said substrate for the same purpose.

Preferred materials for the waveguide are commercially available and include transparent polymers, glass, silicon and fused silica. Useful transparent polymers include polyacetates, polyesters, polyacrylates and methacrylates, polystyrene, and polycarbonates. Desired characteristics of these materials include mechanical and optical stability at typical operating temperatures of the device. Compared with glass, transparent polymers have the added advantage of structural flexibility which allows products to be formed in large sheets and then cut and laminated as necessary. The preferred materials for the substrate 318 are glass and polyester such as poly(ethylene terephthalate). The thickness of the substrate 318 may vary widely. Preferably, the thickness of the substrate 318 is about 1 mil (0.001 inch or 25 microns) to about 10 mil (0.01 inch or 250 microns).

Preferably, the adhesion promoting layer 320 is an organic material which is light transmissive. In some instances, when the index of refraction of the adhesive layer is appropriate, the waveguide core can be formed directly thereon. In other instances, the cladding layer 306 will be formed on the substrate 318. Waveguide cores or cladding formed from polymers, for example photocrosslinked acrylate monomer materials, will preferably adhere strongly to the substrate 318 via the action of the adhesion promoting layer 318. For example, if the substrate 318 is glass and waveguides or cladding are formed from acrylate monomer materials, then an appropriate adhesion promoting layer 320 may be formed by reacting the glass surface with certain types of silane compounds including 3-(trimethoxysilyl)propyl methacrylate; 3-acryloxypropyl trichlorosilane; and trimethylsilylpropylmethacrylate. If the substrate (not shown) is poly(ethylene terephthalate) (PET) and waveguides are formed from acrylate monomer materials for example, the adhesion promoting layer 320 may be provided by using an adhesion treated PET film such as that marketed under the trademark HOSTAPHAN 4500 by Hoechst-Celanese. If the substrate 318 is emulsion coated and the waveguides are formed from acrylate monomer materials, for example, the adhesion promoting layer 320 may be formed from 3-acryloxypropyltrichlorosilane (marketed under the trademark A0396 by Hüls America).

The thickness of the adhesion promotion layer 320 may vary widely according to the application. Preferably, the adhesion promoting layer 320 is less than about 1 micrometer thick. If it is determined that adhesion of the waveguide cores or the cladding to a bare substrate 318 is sufficient, then the adhesion layer 320 may be omitted.

Waveguide cores can be fabricated from photopolymers via a number of techniques such as by exposure through a photomask followed by development to remove unexposed regions. Alternatively the cladding can be embossed with channels which may ultimately be filled with waveguide material to form the waveguide core.

Materials useful for the cladding material in the practice of this invention include thermosetting materials which are known in the art, which include epoxies and thermosetting resins. A representative list of suitable materials may be found in U.S. Patent 5,378,404, the entire contents of which are hereby incorporated by reference. Preferred for use are those thermosetting compounds which are substantially clear, having a low degree of color and haze. Particularly preferred compositions include clear epoxies, polyesters, urethanes, vinyl ethers, and silicones, blends or co-polymers of such compounds and fluorinated derivatives thereof.

Materials useful for the cladding material in the practice of this invention also include thermoplastic materials which are known in the art. A representative list of suitable materials may be found in U.S. Patent 5,378,404, the entire contents of which are hereby incorporated by reference. Preferred for use are those thermoplastic polymers which are substantially clear, having a low degree of color and haze. Particularly preferred compositions include high clarity grades of acrylics, such as PMMA, polycarbonates, polystyrene, polyesters, and poly(vinyl chloride), including co-polymers, blends and alloys of such polymers, and fluorinated derivatives thereof.

In more detail, photopolymerizable materials for the fabrication of cladding 306 and core 304 comprise two main components. The first main component is a photopolymerizable monomer, especially an ethylenically unsaturated monomer, which will provide a transparent solid polymer material. Preferred solid polymer materials have an index of refraction between about 1.45 and about 1.65 and include commercially available polymethylmethacrylate, polycarbonate, polyester, polystyrene, and polymers formed by photopolymerization of acrylate or methacrylate monomers. More preferred materials have an index of refraction between about 1.48 and about 1.60 and include polymers formed by photopolymerization of acrylate monomer mixtures composed of urethane acrylates and methacrylates, ester acrylates and methacrylates, epoxy acrylates and methacrylates, poly(ethylene glycol) acrylates and methacrylates and vinyl containing organic monomers. A mixture of monomers in the photopolymerizable mixture can be used to fine tune the properties of the composition, e.g., to fine tune crosslinking density, viscosity, adhesion, curing rate, and refractive index and to reduce discoloration, cracking, and delamination properties of the photopolymer formed from the composition.

Examples of more preferred monomers include: methyl methacrylate; n-butyl acrylate (BA); 2-ethylhexyl acrylate (EHA); isodecyl acrylate; 2-hydroxyethyl acrylate; 2-hydroxypropyl acrylate; cyclohexyl acrylate (CHA); 1,4-butanediol diacrylate; ethoxylated bisphenol A diacrylate

(EBDA); neopentylglycol diacrylate (NPGDA); diethyleneglycol diacrylate (DEGDA); diethylene glycol dimethacrylate (PEGDMA); 1,6-hexanediol diacrylate (HDDA); trimethylol propane triacrylate (TMPTA); pentaerythritol triacrylate (PETA); pentaerythritol tetra-acrylate (PETTA); phenoxyethyl acrylate (PEA); β-carboxylethyl acrylate (β-CEA); isobornyl acrylate (IBOA); tetrahydrofurfuryl acrylate (THFFA); propylene glycol monoacrylate (MPPGA); 2-(2-ethoxyethoxy) ethyl acrylate (EOEOEA); N-vinyl pyrrolidone (NVP); 1,6-hexanediol dimethacrylate (HDDMA); triethylene glycol diacrylate (TEGDA) or dimethacrylate (TEGDMA); tetraethylene glycol diacrylate (TTEGDA) or dimethacrylate (TTEGDMA); polyethylene glycol diacrylate (PEGDA) or dimethacrylate (PEGDMA); dipropylene glycol diacrylate (DPGDA); tripropylene glycol diacrylate (TPGDA); ethoxylated neopentyl glycol diacrylate (NPEOGDA); propoxylated neopentyl glycol diacrylate (NPPOGDA); aliphatic diacrylate (ADA); alkoxylated aliphatic diacrylate (AADA); aliphatic carbonate diacrylate (ACDA); trimethylolpropane trimethacrylate (TMPTMA); ethoxylated trimethylolpropane triacrylate (TMPEOTA); propoxylated trimethylolpropane triacrylate (TMPPOTA); glyceryl proxylated triacrylate (GPTA); tris (2-hydroxyethyl) isocyanurate triacrylate (THEICTA); dipentaerythritol pentaacrylate (DPEPA); ditrimethylolpropane tetraacrylate (DTMPTTA); and alkoxylated tetraacrylate (ATTA).

Preferred are mixtures wherein at least one monomer is a multifunctional monomer such as a diacrylate or triacrylate, as these will produce a network of crosslinks within the reacted photopolymer. More preferred materials for use in the method of the invention are crosslinked polymers formed by photopolymerizing mixtures of EBDA, HDDA and TPGDA. The index of refraction of the more preferred materials ranges from about 1.53 to about 1.56 for the waveguide core material and from about 1.50 to about 1.54 for the cladding material. In the case of the cladding, it may be advantageous in certain applications to cause inhomogeneities in refractive index, such as striations or domains, to be present because these inhomogeneities may further increase the divergence of light and scattering of stay light which may be propagating within the cladding.

The amount of monomer in the photopolymerizable material may vary widely. The amount of monomer or the total amount of a mixture of monomers is, e.g., from about 60 to about 99.8 percent by weight of the photopolymerizable material, preferably from about 80 to about 99 percent by weight of the photopolymerizable material, and more preferably from about 85 to about 99 percent by weight of the photopolymerizable material.

The second main component of the polymerizable material includes a photoinitiator which is activated by actinic radiation to produce activated species which lead to photopolymerization of the monomer. The photoinitiator system will contain a photoinitiator and preferably a conventional sensitizer which extends the spectral response into regions having spectral utility, e.g., the near ultraviolet region and the visible spectral regions where lasers excite and where many common optical materials are transmissive. Usually the photoinitiator is a free radical-generating addition polymerization initiator activated by actinic light and is preferably thermally inactive at and below room temperatures (e.g., about 20ºC to about 25ºC).

Illustrative of such initiators are those described in U.S. Patent No. 4,943,112, the entire contents of which are hereby incorporated by reference. Preferred free radical initiators are 1-hydroxy-cyclohexyl-phenyl ketone (Irgacure 184); benzoin; benzoin ethyl ether; benzoin isopropyl ether; benzophenone; benzidimethyl ketal (Irgacure 651); α,α-diethyloxy acetophenone, α,α-dimethyloxy-α-hydroxy acetophenone (Darocur 1173); 1-[4-(2-hydroxyethoxy)phenyl]-2-hydroxy-2-methyl-propan-1-one (Darocur 2959); 2-methyl-1-[4-methylthio)phenyl]-2-morpholino-propan-1-one (Irgacure 907); 2-benzyl-2-dimethylamino-1-(4-morpholinophenyl)-butan-1-one (Irgacure 369); poly{1-[4-(1-methylvinyl)phenyl]-2-hydroxy-2-methyl-propan-1-one} (Esacure KIP); [4-(4-methylphenylthio)-phenyl]phenylmethanone (Quantacure BMS); di-campherquinone; and 50% 1-hydroxycyclohexyl phenyl ketone and 50% benzophenone (Irgacure 500).

The more preferred photoinitiators include: benzidimethyl ketal (Irgacure 651); α,α-diethyloxy acetophenone; α,α-dimethyloxy-α-hydroxy acetophenone (Darocur 1173); 1-hydroxy-cyclohexyl-phenyl ketone (Irgacure 184); 1-[4-(2-hydroxyethoxy)phenyl]-2-hydroxy-2-methyl-propan-1-one (Darocur 2959); 2-methyl-1-4-(methylthio)phenyl]-2-morpholino-propan-1-one (Irgacure 907); 2-benzyl-2-dimethylamino-1-(4-morpholinophenyl)butan-1-one (Irgacure 369); and 50% 1-hydroxycyclohexyl phenyl ketone and 50% benzophenone (Irgacure 500). The most preferred photoinitiators are those which tend not to yellow upon irradiation and, thus, do not increase the coloration of the composition on the Gardner scale to a value of greater than 8 points on exposure to a temperature of 190ºC for 24 hours as determined by ASTM D1544-80. Such photoinitiators include benzidimethyl ketal (Irgacure 651); α,α-dimethyloxy-a-hydroxy acetophenone (Darocur 1173); 1-hydroxy-cyclohexyl-phenyl ketone (Irgacure-184); 1-[4-(2-hydroxyethoxy)phenyl]-2-hydroxy-2-methyl-propan-1-one (Darocur 2959); and 50% 1-hydroxycyclohexyl phenyl ketone and 50% benzophenone (Irgacure 500).

The amount of photoinitiator which should be present ranges, e.g., from about 0.1 to about 12 percent by weight based on the total weight of the photopolymerizable material. The amount of photoinitiator is preferably from about 0.5 to about 12 percent by weight, and more preferably from about 0.5 to about 6 percent by weight based on the total weight of the photopolymerizable material. It is realized that the desired amount of photoinitiator will also be influenced by the choice of irradiating wavelengths present in the exposure source, which may be controlled by those skilled in the art.

In addition to the main components, the photopolymerizable material may include various optional components such as stabilizers, inhibitors, plasticizers, optical brightners, release agents, chain transfer agents, other photopolymerizable monomers, and the like.

The photopolymerizable material preferably includes a stabilizer to prevent or reduce degradation which leads to property deterioration such as cracking and delamination after heat aging at 190ºC in air for 24 hours, as defined by ASTM D 4538-90A and yellowing (coloration of greater than 8 on the Gardner Color Scale as determined by ASTM D 1544-80) after such heat aging. Such stabilizers include UV absorbers, light stabilizers, and antioxidants.

The UV absorbers include hydroxyphenyl benzotriazoles, such as 2-[2-hydroxy-3,5-di(1,1-dimethylbenzyl)phenyl]-2-H-benzotriazole (Tinuvin 900); Poly(oxy-1,2-ethanediyl), α-(3-(3-(2H-benzyotriazol-2-yl)-5-(1,1-dimethylethyl)-4-hydroxyphenyl)-1-oxopropyl)-ω-hydroxy (Tinuvin 1130); and 2-[2-hydroxy-3,5-di(1,1-dimethylpropyl)phenyl]-2-H-benzotriazole (Tinuvin 238) and hydroxybenzophenones such as 4-methoxy-2-hydroxybenzophenone and 4-n-octoxy-2-hydroxybenzophenone.

The light stabilizers include hindered amines such as 4-hydroxy-2,2,6,6-tetramethylpiperidine, 4-hydroxy-1,2,2,6,6-pentamethylpiperidine, 4-benzoyloxy-2,2,6,6-tetramethylpiperidine, bis(2,2,6,6-tetramethyl-4-piperidinyl)sebacate (Tinuvin 770); bis(1,2,2,6,6-pentamethyl-4-piperidinyl)sebacate (Tinuvin 292); bis(1,2,2,6,6-pentamethyl-4-piperidinyl)-2-n-butyl-2-(3,5-di-tert-butyl-4-hydroxybenzyl)malonate (Tinuvin 144); and polyester of succinic acid with N-β-hydroxy-ethyl-2,2,6,6-tetramethyl-4-hydroxy-piperidine (Tinuvin 622).

The antioxidants include substituted phenols such as 1,3,5-trimethyl-2,4,6-tris(3,5-di-tert-butyl)-4-hydroxybenzyl)benzene, 1,1,3-tris-(2-methyl-4-hydroxy-5-tert-butyl)phenyl)butane, 4,4'-butylidene-bis-(6-tert-butyl-3-methyl)phenol, 4,4'-thiobis-(6-tert-butyl-3-methyl)phenol, tris-(3,5-di-tert-butyl-4-hydroxybenzyl)isocyanurate, cetyl-3,5-di-tert-butyl-4-hydroxybenzene (Cyasorb UV2908); 3,5-di-tert-butyl-4-hydroxybenzoic acid, 1,3,5-tris-(tert-butyl-3-hydroxy-2,6-dimethylbenzyl) (Cyasorb 1790); stearyl-3-(3,5-di-tert-butyl-4-hydroxyphenyl)proprionate (Irganox 1076); pentaerythritol tetrabis(3,5-di-tert-butyl-4-hydroxyphenyl) (Irganox 1010); and thiodiethylene-bis-(3,5-di-tert-butyl-4-hydroxy)hydrocinnamate (Irganox 1035).

The more preferred stabilizers for the invention are antioxidants. Preferred antioxidants are selected from substituted phenols such as 1,3,5-

trimethyl-2,4,6-tris(3,5-di-tert-butyl)-4-hydroxybenzyl)benzene, 1,1,3-tris-(2-methyl-4-hydroxy-5-tert-butylphenyl)butane, 4,4'-butylidene-bis-(6-tert-butyl-3-methylphenol, 4,4'-thiobis-(6-tert-butyl-3-methylphenol, tris-(3,5-di-tert-butyl-4-hydroxybenzyl)isocyanurate, cetyl-3,5-di-tert-butyl-4-hydroxybenzene (Cyasorb UV 2908); 3,5-di-tert-butyl-4-hydroxybenzoic acid, 1,3,5-tris-tert-butyl-3-hydroxy-2,6-dimethylbenzyl) (Cyasorb 1790); stearyl-3-(3,5-di-tert-butyl-4-hydroxyphenyl)proprionate (Irganox 1076); pentaerythritol tetrabis(3,5-di-tert-butyl-4-hydroxyphenyl) (Irganox 1010); and thiodiethylene-bis-(3,5-di-tert-butyl-4-hydroxy)hydrocinnamate (Irganox 1035). The most preferred stabilizers include: pentaerythritol tetrabis(3,5-di-tert-butyl-4-hydroxyphenyl) (Irganox 1010); thiodiethylene-bis-(3,5-di-tert-butyl-4-hydroxy)hydrocinnamate (Irganox 1035); and stearyl-3-(3,5-di-tert-butyl-4-hydroxyphenyl)proprionate (Irganox 1076).

The amount of stabilizers in the composition may vary widely and is usually, e.g., from about 0.1 to about 10 percent by weight of the photopolymerizable material. The amount of stabilizer is preferably from about 0.1 to about 5 percent by weight of the photopolymerizable material and more preferably from about 0.2 to about 3 percent by weight of the photopolymerizable material.

Figures 5A-5E depict steps of a preferred method for forming the array of waveguides according to the invention. It is noted that the method is equally applicable to forming a single waveguide. However, the advantages of the method are greater when applied to an array.

In Figure 5A, a layer 502 of cladding material including light absorbent particles is provided. The material for the layer 502 also is preferably thermoplastic polymer or thermally-curable or UV-curable monomer or oligomer. An example of material well suited to layer 502 is poly(methyl methacrylate), also known as PMMA. Preferably, the layer 502 is thick enough to be self supporting, i.e., having independent structural integrity. Alternatively, the layer 502 could be formed on a substrate if the layer 502 were not sufficiently thick to be self-supporting.

In Figure 5B, channels or recesses 504, preferably square (depicted), trapezoidal, or hemispherical (not depicted) in cross-section, are formed in the cladding layer 502. Simultaneous with the formation of the channels 504, halo regions 506 are formed. The simultaneous formation of the channels 504 and the halo regions 506 will be discussed in more detail below.

In Figure 5C, core material 508, which is preferably clear, is formed in the recesses 504 to form the cores 508. A surface defined by the cores 508 and the cladding layer 502 is substantially planar. In Figure 5D, a layer of preferably clear cladding material is formed on the surface defined by the cores 508 and the cladding layer 502. In Figure

5E, a layer 512 containing light absorbent particles is optionally, albeit preferably, formed on the second cladding layer 510.

The second cladding layer 510 and the layer 512 containing light absorbent particles can be formed of thermally-curable or UV-curable material Examples of the material for the layers 502, 510 and 512 are epoxies and acrylates. The layer 512 of material containing light absorbent particles preferably has an index of refraction that is equal to or slightly higher than the second layer of cladding 510.

A number of processes can be used to simultaneously form the channels 504 and the halo regions 506 in the first layer of cladding material 502, as depicted in Figure 5B. These processes include injection molding, vacuum-assisted injection molding, compression-injection molding, compression molding, thermoforming, extrusion, thermal embossing and soft embossing. For thermoplastics, the compression-injection molding process is preferred because it is the most commercially viable, and will be discussed first.

In compression-injection molding, molten cladding material, such as PMMA, is injected into a heated mold under pressure. Such a mold 702 is depicted in Figure 7.

The mold 702 is depicted as in Figure 7 as being formed from an upper piece 704 and a lower piece 706. It is necessary for the mold to be formed in at least two pieces so that the molded article can be removed. For example, the molten cladding material can be injected through the port 708 in the second-half 706 of the mold 702.

The mold 702 is shaped as the compliment of the intermediate structure depicted in Figure 5B. Here, the cladding layer 502 having the channel 504 of Figure 5B is a female structure and the mold 702 is the complementarily shaped male structure.

The dimensions involved are very small. Compression-injection molding and vacuum-assisted-injection molding appear more commercially viable than basic injection molding because these fill small voids more effectively.

According to the physics of fluid flow under laminar flow conditions, the layer of fluid immediately adjacent to a surface (whose normal direction lies substantially perpendicular to the flow direction) is stationary or moves slowly compared with fluid farther from the surface. Accordingly, particles in the fluid tend to be drawn into the more rapidly flowing regions. This tendency is stronger for larger particles which are subject to a greater differential of fluid velocities across opposing faces of the particle. The effect is also enhanced for particles having a high aspect ratio, which is defined as the ratio of longest to shortest dimension. Thus, the light absorbent particles in the cladding material move away from the surfaces of the mold pieces 704 and 706, which produces the halo regions 308 around the ridge 710 on the mold piece 704. To restate, the halo regions 308 are regions of the cladding material that are substantially depleted of the light absorbent particles. These halo regions 308 can be referred to as an unfilled skin of the cladding material.

For compression-injection molding, the unfilled skin effect will be predominately manifested against all of the surfaces of the mold 702 whose surfaces lie substantially perpendicular to the flow direction during the injection phase. Accordingly, injection ports 708 of the mold are preferably located at points designed to maximize the flow over the waveguide defining regions 710 and to create a flow direction which is substantially parallel to the nascent waveguide direction, i.e., perpendicular to the cross-section of Fig. 7. The expected result is depicted in Figure 8, where an intermediate array structure 802 having a first layer of cladding material 804 is depicted as having a contiguous halo region 806 around the exterior surfaces of the layer of cladding material 804. In Figure 3, discrete regions 308 have been depicted because they represent the optically significant portions of the halo region 806, and because some of the embodiments for forming the halo regions 308 do not produce a contiguous halo region such as that shown in Figure 8.

An alternative process for forming the channel 504 in the cladding material 502 (as depicted in Figure 5B) is embossing, that is, either thermal embossing or soft embossing. In thermal embossing, the cladding layer 502 is formed as a layer on a substrate or preferably a carrier web. The material of the cladding layer 502 is a thermoplastic formed, e.g., via extrusion, co-extrusion, solvent coating or extrusion coating. Extrusion methods are preferred since they will promote the formation of an unfilled skin on the surface of the cladding. This originally formed unfilled skin will tend to be preserved during the subsequent embossing step.

Figure 6 depicts an example of how one of the channels 504 of Figure 5B is embossed into the cladding layer 502 of Figure 5B. To simplify the drawing, only a single ridge 608, that forms one of the channels 504, has been depicted. In Figure 6, a carrier web 604 having the cladding layer thereon is tensioned partly around an embossing cylinder or drum 602. Around the circumference of the drum 602 is a ridge 608, depicted in phantom lines because it is beneath the web 604. The ridge is the male complement to the female channel that is to be formed.

The drum 602 and ridge 608 is heated such that when it makes contact with the web 604, the portion of the cladding layer in contact with surface 602 and the ridge 608 softens or melts adjacent to the ridge 608 and at least localized flow takes place. This flow causes the halo region 508 of Figure 5B to be formed. Thermal embossing is an example of a process for forming the channel which tends to produce discrete halo regions 506 rather than the contiguous halo region 806 depicted in Figure 8.

As the web moves around the drum 602, it reaches a point where it is no longer in contact with the face 606 of the drum 602. Soon thereafter, the locally melted portion of the cladding layer on the web 604 solidifies, which results in the channel 504 having adjacent halo regions 506, as depicted in Figure 5B.

An alternative to the thermal embossing technique is the soft embossing technique. In soft embossing, the cladding layer 502 is UV-curable or thermally-curable. The cladding material is formed on the web 604 in an uncured, i.e., at least semi-liquid state (e.g., viscosity greater than about 100 centipoise (cp)). As the web moves into contact with the face 606 of the drum 602, the ridge 608 (which does not have to be heated) is inserted into the uncured cladding material so that at least localized flow takes place and the halo regions 506 are formed. Again, extrusion coating or slot coating of the carrier web before embossing will enhance the desired effect by pre-establishing an unfilled skill.

Before the web looses contact with the face 606 of the drum 602, it passes in front of a source 610 of either UV or thermal (e.g., infrared (IR)) radiation which cures the cladding material. The cladding material on the web 604 is sufficiently cured by the time the web 604 looses contact with the face 606 of the drum 602 so that the shape of the channel 504 and the absorbent-particle-depleted nature of the halo regions 506 is retained. Thus, the soft embossing technique is another example of a process which tends to produce discrete halo regions 506 rather than the contiguous halo region 806 depicted in Figure 8.

For either embossing technique, to accurately emboss the ridge 608 into the cladding layer on the web 604, it might be necessary to use an opposing drum or cylinder 612. Such a drum 612 is depicted in phantom lines to reinforce that this is an optional aspect of the process.

For the techniques that simultaneously form channels and halo regions, discussed above, the thickness of the halo regions will vary in direct proportion to the degree to which flow is established next to the ridge 608. The degree to which flow is established is dependent upon the design of the pattern to be embossed and the thickness of the organic liquid coating on the web compared to the thickness of the cured and embossed cladding material. Moreover, for thermal embossing, the degree to which flow is established is based also upon the temperature of the ridge 608. Generally, embossing techniques are less preferred then injection and extrusion techniques because the degree of flow is substantially less. Nevertheless, embossing techniques can be effective, especially when employed with an extrusion or slot coated carrier web technique, which can produce a relatively filler-particle-free surface which will tend to be preserved in the embossed product.

The desired surface chemistry of the light absorbent particles in the cladding according to the invention is contrary to the prior art of dispersed particulate composites. In the prior art, it is desirable to minimize the mismatch between surfaces energies of the mixed materials to the greatest extent possible in order to promote uniformity in the distribution of particles within a base medium. In contrast, the invention seeks to promote non-uniformity of mixture, specifically in the form of the halo regions 506 or 806. To promote such non-uniformity, it is necessary to preserve a certain degree of mismatch in surface energy between the light absorbent particles and the matrix material. However, the surface energy mismatch must not be made so great as to induce agglomeration, i.e., clumping, of the light absorbent particles within the matrix material.

The size and shape of the particles is critical. It is required that at least one dimension of the particle be larger than the desired thickness of the unfilled skin and larger than the thickness of the relatively stationary fluid layer which lies immediately adjacent to the surface of the mold, die, or embossing tool during the critical forming step. Particle size is preferably in a range from 1 to 30 microns and more preferably in a range from 3 to 20 microns. Particles with a high aspect ratio, i.e., the ratio of longest dimension divided by shortest dimensions, are preferred. Particles having an aspect ratio greater than 5 are preferred, more preferred are particles having an aspect ratio greater than 10, even more preferred are particles having an aspect ratio greater than 50.

A waveguide exhibiting the unfilled skin effect, i.e., having a halo region in the cladding, according to the invention, is applicable to optically interconnected photonic systems, connectors, imaging systems, and display systems. Photonic systems include photonic devices, e.g., a directional coupler or splitter. A photonic device includes a waveguide. Examples of imaging systems include one or two dimensional arrays of waveguides suited for bar-code scanning, image scanning, machine vision or the like. Where crosstalk in photonic systems is a problem, the use of a waveguide according to the invention can significantly reduce such crosstalk. The present invention is also suitable for forming a black matrix for a display optic, projection screen, or a light collimator. Such examples are typically characterized by a short waveguide which is oriented normal to the plane of a substrate or the viewing screen.

Yet another alternative technique for forming the array of waveguides 302 of Figure 3 is as follows. Provide a first cladding layer having light absorbent particles therein and an array of parallel channels. Form a second layer of clear cladding material against the bottom and sides of the channels by a second molding or embossing step. Form cores in the remainders of the channels. This technique will be referred to as the protracted method.

The protracted method can be carried out via the deposition of a conformal coating, but such an approach is time consuming and is restricted with regard to useful materials. The protracted method can also be carried out in multiple molding steps in which the array of channels must be aligned, or registered, between steps. Such alignment requires extremely high precision because of the very small dimensions under consideration. The need for repeated registrations makes the protracted method much less commercially viable than the methods discussed above. The preferred methods discussed above do not require registration, i.e., alignment of an array of pre-existing channels with a pattern of a second mold or embossing total.

The waveguide exhibiting an unfilled skin effect according to the invention has the advantage of promoting the propagation of desired light and filtering out undesired light. In addition, the preferred methods of forming an array of such waveguides according to the invention have the advantage of being commercially viable.

The invention being thus described, it will be obvious that the same may be varied in many ways. Such variations are not to be regarded as a departure from the spirit and scope of the invention, and all such modifications as would be obvious to one skilled in the art are intended to be included within the scope of the following claims.

We claim:

1. A waveguide comprising a cladding layer and a core, said cladding layer having at least one of light scattering particles or light absorbent particles distributed therein, said cladding layer also having a halo region located around said core, said halo region being depleted of said light scattering and said light absorbent particles.

2. The waveguide of claim 1, wherein said cladding layer is a first cladding layer and said first cladding layer is located around three sides of said core, and wherein a fourth side of said core and said first cladding layer together define a surface, said waveguide further comprising a second cladding layer formed on said surface.

3. The waveguide of claim 2, further comprising a light absorbent layer on said second cladding layer.

4. The waveguide of claim 1, wherein said waveguide has a planar input face and a portion of said waveguide bends out of a plane normal to said planar face to promote propagation of unwanted light into regions of said cladding having said light scattering particles or said light absorbent particles, respectively.

5. A waveguide structure comprising:

an array of waveguides, each of said waveguides having a cladding layer and a core,

said cladding layer having at least one of light scattering particles or light absorbent particles distributed therein, said cladding layer also having a halo region around said core, said halo region being depleted of said light scattering particles and said light absorbent particles.

6. The structure of claim 5, wherein said array of waveguides has a planar input face and portions of said waveguides bend out of a plane normal to said planar face to promote propagation of unwanted light into regions of said cladding layer having said light scattering particles or said light absorbent particles, respectively.

7. The structure of claim 5, wherein said cladding layer is a first cladding layer and said first cladding layer is located around three sides of said core, and wherein a fourth side of said core and said first cladding layer together define a surface, said waveguide structure further comprising a second cladding layer formed on said surface.

8. The structure of claim 7, further comprising a light absorbent layer on said second cladding layer.

9. The structure of claim 5, wherein said halo region has a thickness, t, in a range from one to ten microns.

10. The structure of claim 5, wherein sizes of said light scattering particles or said light absorbent particles are larger than one micron.

11. The structure of claim 10, wherein said sizes of said light scattering particles or said light absorbent particles are larger than three microns.

12. The structure of claim 11, wherein said sizes of said light scattering or said light absorbent particles are larger than ten microns.

13. The structure of claim 5, wherein said light absorbent particles are at least one of carbon black particles, graphite fibers, a black pigment, and black dyed particles.

14. The structure of claim 5, wherein said scattering particles or said light absorbent particles have an aspect ratio greater than five.

15. The structure according to claim 14, wherein said light scattering particles or said light absorbent particles have an aspect ratio greater than fifty.

16. A method of forming an array of waveguides having cladding that exhibits an unfilled skin effect, the method comprising:

a) forming a first cladding layer of cladding material having at least one of light scattering particles and light absorbent particles therein;

b) forming grooves in said first cladding layer such that halo regions depleted of said light scattering particles and said light absorbent particles are formed in said first cladding layer around said grooves, respectively; and

c) forming cores in said grooves.

17. The method as in claim 16, further comprising: forming a second cladding layer on said first cladding layer and said cores.

18. The method as in claim 17, further comprising:
forming a light absorbent layer on said second cladding layer.

19. The method of claim 16, wherein said steps a) and b) are performed concurrently in an injection molding process.

20. The method of claim 19, wherein said injection molding process is a compression-injection molding process.

21. The method of claim 16 wherein said step (a) uses an extrusion process.

22. The method of claim 16 wherein a combination of said steps a) and b) use an extrusion process.

23. The method of claims 16, wherein said step b) uses a thermal embossing process.

24. The method of claims 16, wherein said step b) uses a soft embossing process such that said first cladding layer is ultraviolet (UV) light-curable or thermally curable.

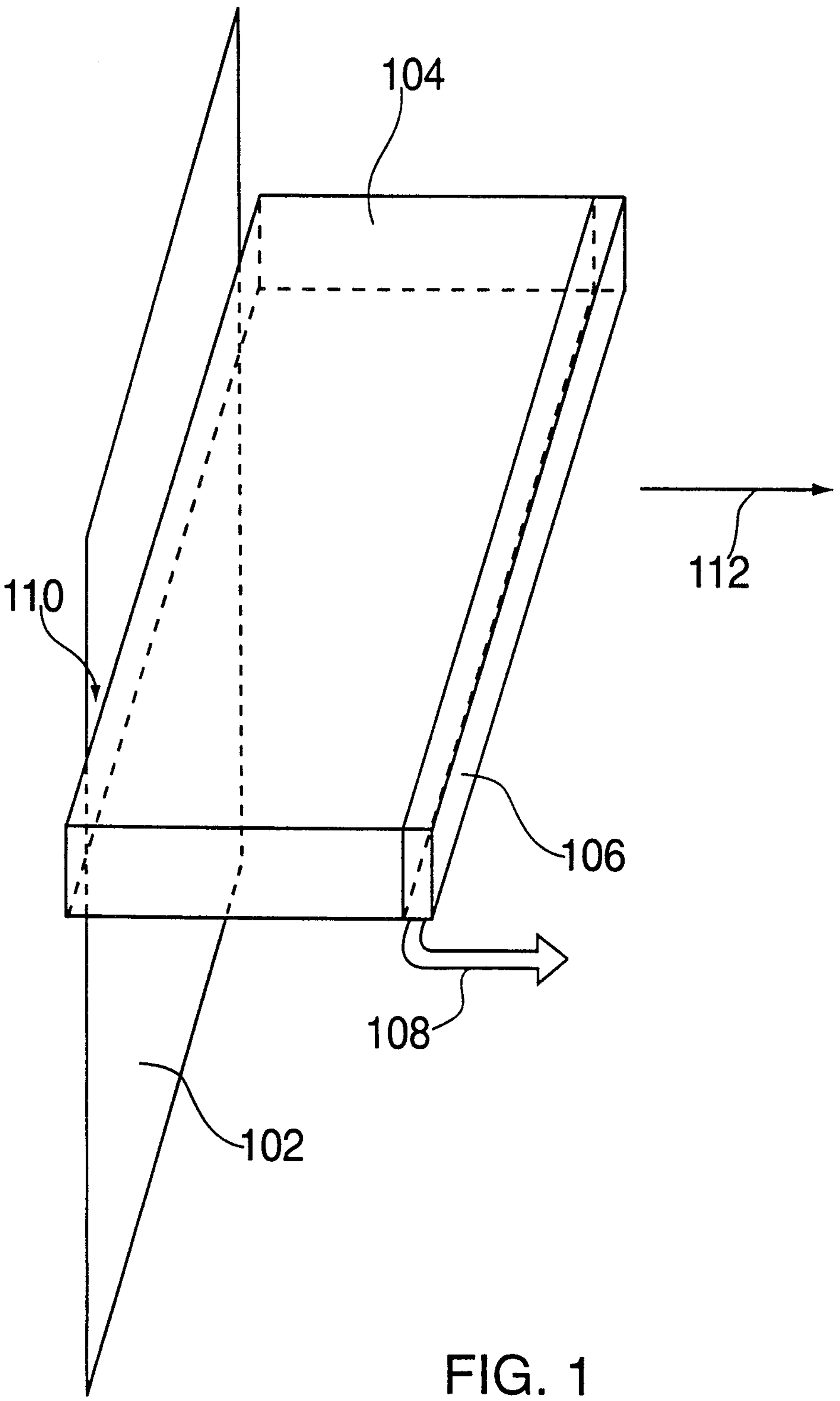

FIG. 1

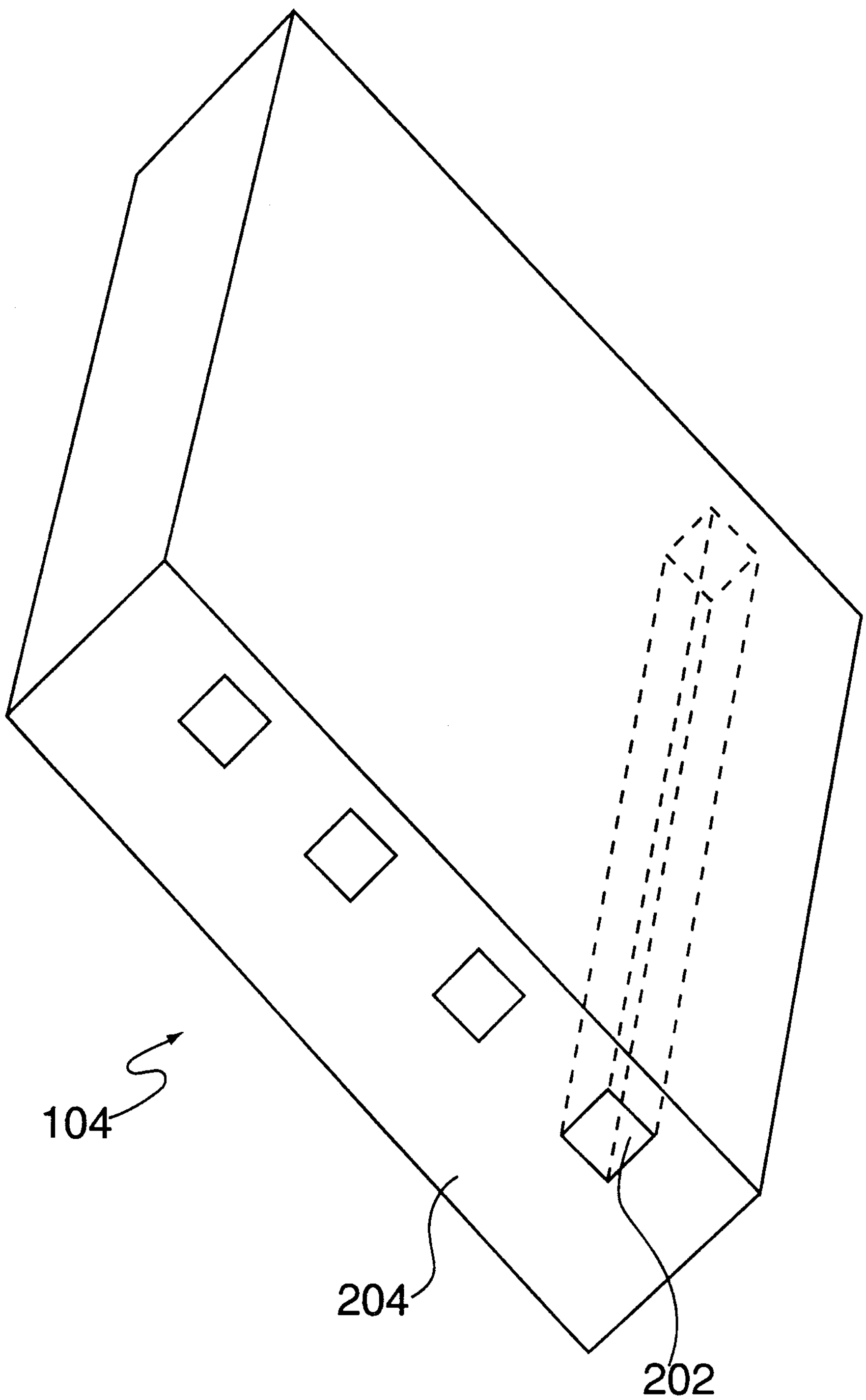

FIG. 2

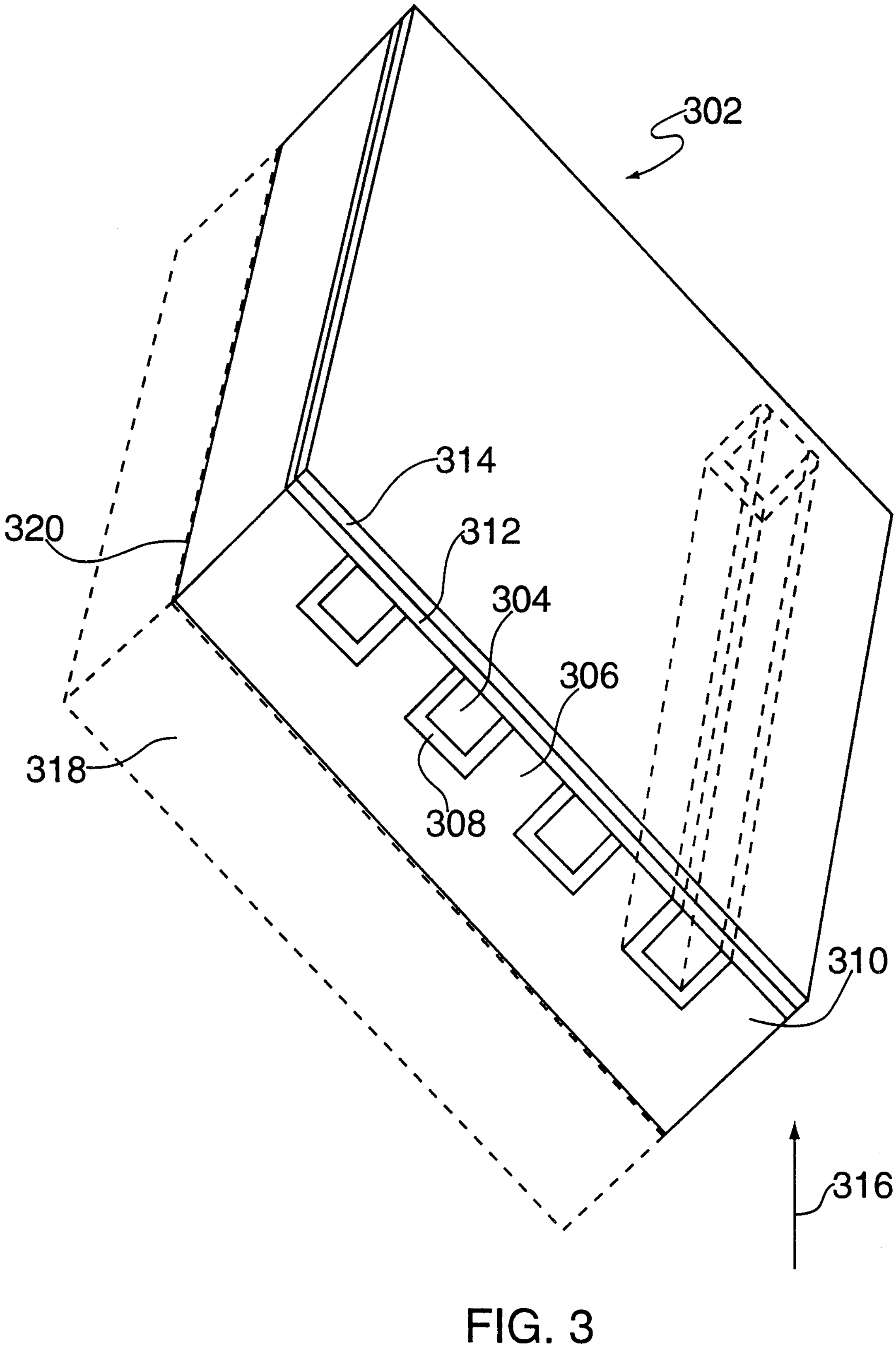

FIG. 3

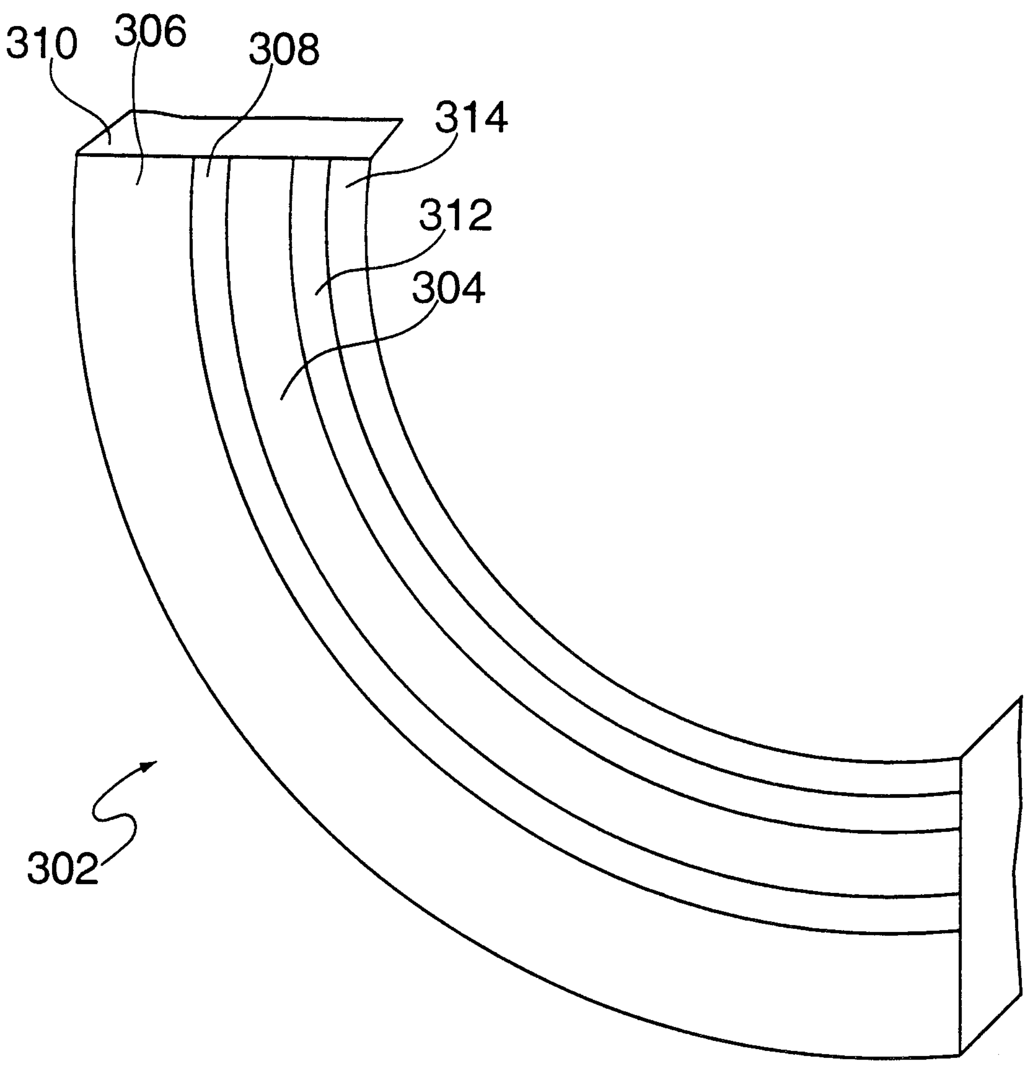

FIG. 4

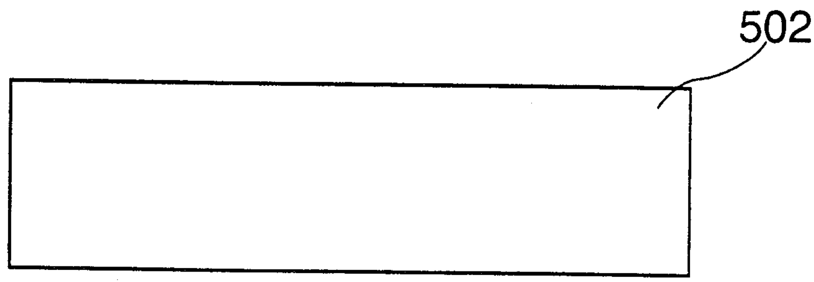

FIG. 5A

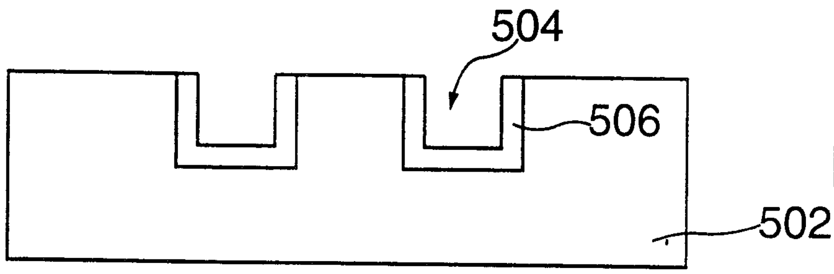

FIG. 5B

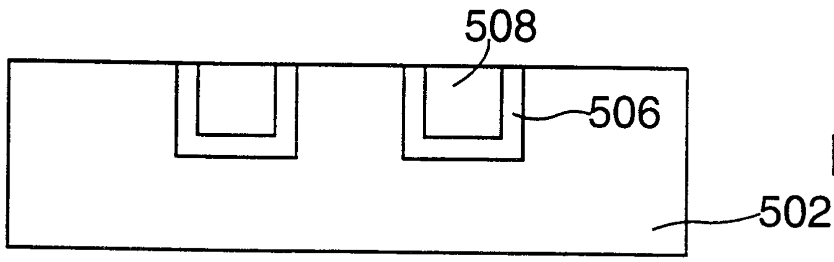

FIG. 5C

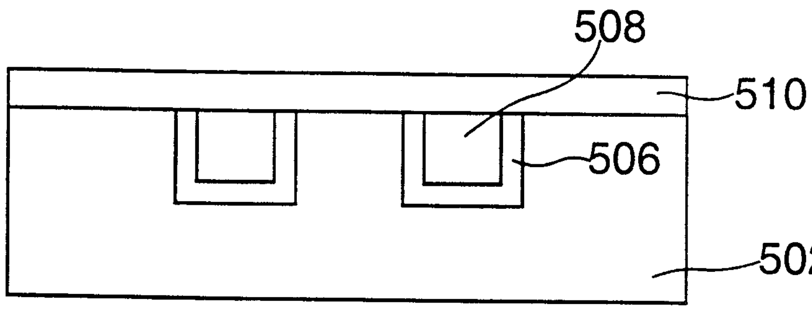

FIG. 5D

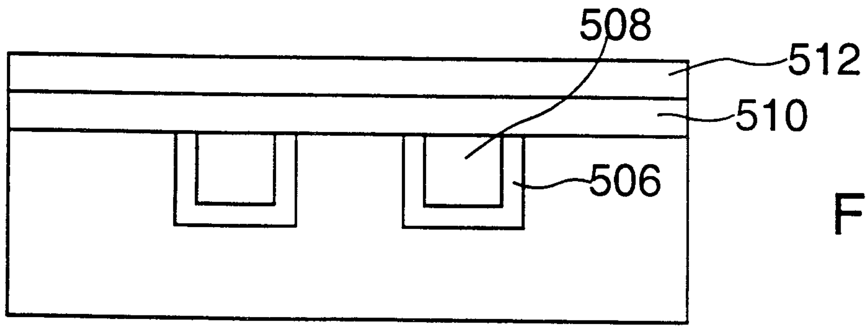

FIG. 5E

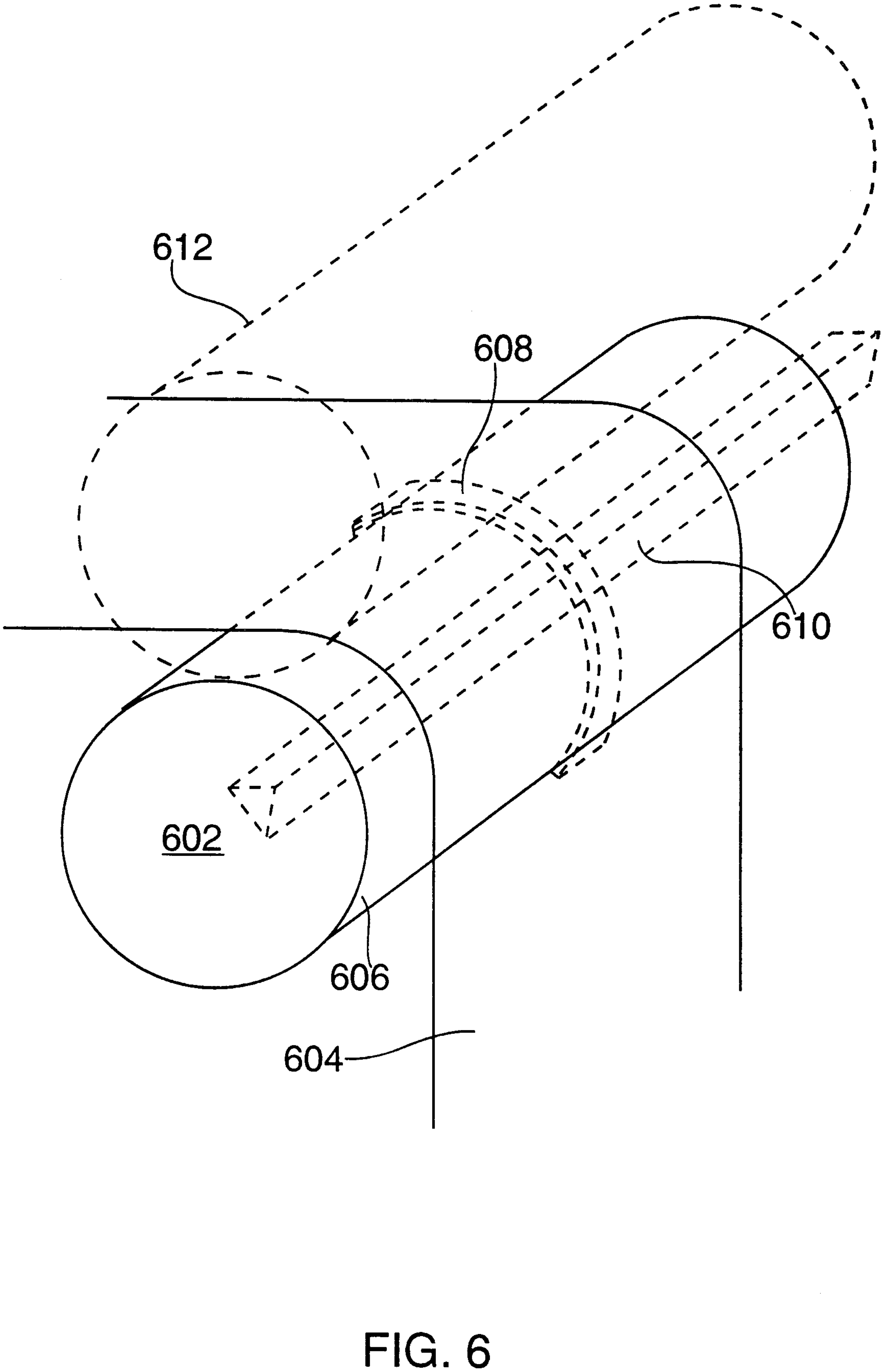

FIG. 6

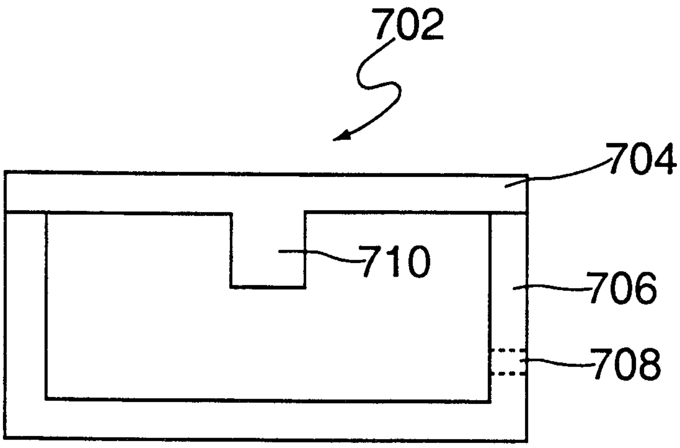

FIG. 7

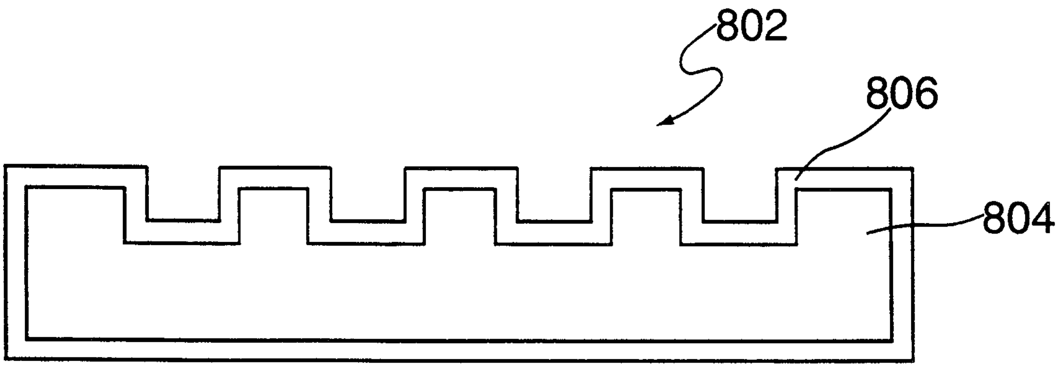

FIG. 8

INTERNATIONAL SEARCH REPORT

Inte onal Application No
PCT/US 99/05045

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 G02B6/12 G02B6/08

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 G02B B29D

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 practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X A	US 5 113 470 A (FUKUSHIMA TETSUO ET AL) 12 May 1992 see the whole document ---	1-3,5,7, 8,16,17 24
A	PATENT ABSTRACTS OF JAPAN vol. 016, no. 266 (P-1371), 16 June 1992 & JP 04 067103 A (BROTHER IND LTD), 3 March 1992 see abstract ---	2,3,7,8
X	DATABASE WPI Section Ch, Week 9223 Derwent Publications Ltd., London, GB; Class A89, AN 92-189487 XP002106206 & JP 04 125502 A (HITACHI CABLE LTD) , 27 April 1992 see abstract --- -/--	1,5, 9-11,13, 16,19

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
16 June 1999	28/06/1999

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Ciarrocca, M

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INTERNATIONAL SEARCH REPORT

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C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

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X A	US 5 719 981 A (KATOH IKUO ET AL) 17 February 1998 see column 6, line 61 - line 66; figures 3,4	1 10,11,13
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