

PATENT SPECIFICATION

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(54) OPTICAL ELEMENT

(71) We, EASTMAN KODAK COMPANY, a Company organized under the Laws of the State of New Jersey, United States of America of 343 State Street, Rochester, New York 14650, United States of America do hereby declare the invention for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to optical elements.

Various synthetic organic plastics materials have been used in the manufacture of certain types of optical elements. These materials, essentially of uniform refractive index, are ground in a manner similar to the grinding of glass lens material to impart the necessary curvature to the optical faces thereof. United States Patent Specifications Nos. 2,430,550 and 3,194,116 disclose various copolymers containing styrene which may be used to form optical lenses with curved optical surfaces obtained by grinding.

United States Patent Specification No. 3,485,556 describes a multi-focal ophthalmic lens which is apparently made by a conventional grinding or moulding process from a non-homogeneous solid material in which there exists a transition zone of refractive index gradient from a higher-index first polymer to a lower-index second polymer, the transition zone comprising a copolymeric portion having variable composition. This material is made from monomeric liquids which undergo mutual diffusion and are subsequently polymerized. However, even in this type of plastics lens elements, suitable surface curvature is essential to provide lens-like action.

Various glass optical lenses which utilize diffusion of inorganic components, such as the exchange of metal ions, on a curved glass surface to produce a uniform increase in refractive index at these glass surfaces are also known, and are discussed, for example, in United States Patent Specification No. 3,486,808.

The use of synthetic organic plastics materials

instead of glass in the manufacture of various types of optical and other lens-like media has many potential advantages. Generally, the plastics materials are less expensive than the optical glass, and finishing operations such as polishing are usually more difficult to perform on glass optical elements, it being possible to produce plastics lenses by moulding the final shape. Of course it is somewhat difficult to find plastics materials which possess the necessary physical and mechanical properties which render them suitable for forming conventional plastics optical elements therefrom. Much of this difficulty is due to the fact that the optical surfaces thereof must be properly curved.

The present invention provides a synthetic organic plastics element which is suitable, for example, for use as a lens element or a light-guiding element without the necessity of utilizing a precisely curved surface.

In accordance with the present invention, there is provided a transparent element for the deflection of incident electromagnetic radiation, comprising a shaped transparent polymeric matrix of a homogeneous glassy amorphous polymer and a transparent diluent within the matrix forming a continuous gradient in refractive index extending in a direction substantially perpendicular to an optical axis extending through the element, the diluent comprising an organic liquid having a molecular weight of less than 1000 which possesses an index of refraction different from that of the polymer and which is incapable of inducing crystallization of the polymer.

In one embodiment of the invention, the optical axis of the polymeric matrix extends between two optical surfaces which are substantially flat and aligned in a substantially parallel relationship with one another.

Elements in accordance with the invention, which are capable of lens-like focussing action without any curvature of their optical surfaces, can advantageously be combined with conventional lens-making technology, e.g. grinding and moulding, to form lenses having curved

surfaces but which possess lens properties otherwise difficult to achieve, or unattainable, using conventional lens-making processes alone.

In the present specification and claims, the term "optical axis" means an imaginary line which extends internally through the polymeric matrix of the elements of the invention and which passes through the centres of curvature of that portion of the end surfaces of the polymeric matrix which is adapted for the passage of incident light. In an embodiment of the invention wherein at least one of the end surfaces is substantially flat, the flat surface may be considered as portions of a sphere of infinite radius, and the optical axis will be an imaginary line extending through the matrix and substantially perpendicular to the flat surface.

An element in accordance with the present invention may have more than one optical axis. In such case these multiple axes will pass through the centres of curvature of the end surfaces of the polymeric matrix; however, in such case, each end surface of the matrix will in effect contain multiple centres of curvature; i.e. one centre of curvature for each optical axis.

The term "optical surface" in the present specification and claims means a surface or surface portion of an element in accordance with the present invention which is specifically provided as a window for the passage of electromagnetic radiation, such as light, which is to be deflected by the element.

In order that the invention may be more clearly understood, illustrative embodiments thereof will now be described with reference to the accompanying drawings, in which:

Figure 1 shows a first embodiment of the polymeric matrix used in the invention, the matrix being in the form of a hollow symmetrical cylinder. Distribution of the diluent into the matrix has not yet occurred.

Figure 2 shows a side view of an optical element prepared from the matrix of Figure 1, showing the effect which it has upon incident electromagnetic radiation.

Figure 3 shows a second embodiment of the polymeric matrix used in the invention, this matrix having the form of an annular element.

Figure 3-A shows a variation of the embodiment of Figure 3. Distribution of the diluent in the matrix is not depicted in either Figure 3 or Figure 3-A.

Figure 4 shows a third embodiment of the invention wherein the diluent is diffused from an external source into a cylindrical polymeric matrix.

Figure 5 shows a fourth embodiment of the invention having planar symmetry, wherein the diluent is diffused into the matrix from an external source.

Figure 6 shows a further embodiment having planar symmetry, wherein the diluent is diffused into the matrix from a central cavity.

Distribution of the diluent within the matrix is not depicted in any of Figures 4, 5 or 6.

Figure 7 and 8 illustrate wave guide systems utilizing a continuous series of elements in accordance with the present invention.

Figure 9 shows an element in accordance with the invention having multiple optical axes.

Figure 10 shows an element in accordance with the invention having a reflective backing layer.

In Figure 1 there is shown an embodiment of the invention in the course of preparation, comprising a hollow polymeric matrix 93 in the form of a symmetrical cylinder. The optical surface 92 of the cylinder is large compared with the size of a bundle of incident light rays, and is substantially flat and parallel to the optical surface 94.

An angularly symmetrical radial gradient of refractive index substantially proportional to the radial distance perpendicular to the optical axis 90 will be formed in the matrix by the diffusion of a diluent 91 into the matrix from the central core 14.

Referring now to Figure 2, which is a side view of the element of Figure 1 showing the passage of parallel rays of light 16 therethrough after the diffusion of the diluent into the matrix has occurred, the refractive index varies radially in a nonlinear manner. At constant radius the refractive index is substantially independent of angular displacement, and the refractive index (at constant radius) is independent of distance parallel to the optical axis 90 of the cylinder.

No central core is indicated in Figure 2, because after diffusion of the diluent from the central core into the matrix occurs, the original boundary between core and matrix is no longer observable, as will be further explained hereinafter.

The formula governing the ray travel in the cylindrical element illustrated in Figure 2 (see page 123 of N. Born and E. Wolf, "Principles of Optics", MacMillan Co., New York 1959) is:

$$1/R = -a_r \cdot \nabla \ln n$$

where R is the radius of curvature of the ray path 16, a_r is the unit outward normal, i.e. a_r is a unit vector normal to the tangent of the ray path 16, and n is the refractive index.

That the gradient in refractive index must be a function of radial displacement arises because of the focussing requirement. If the gradient was independent of radial distance, the parallel rays 16 would all curve through the same angles without focussing to a point 17 (or in the divergent lens case, without having originated from a virtual point). This would be analogous to the action of an isotropic wedge, which is useful for indicating the effects of

dispersion, but not for illustrating focussing action. (Exempted from consideration in the latter category is the wedge of revolution, often called a conical axicon lens).

5 Consideration of the above equation indicates that useful focussing occurs for a refractive index n , proportional to r^2 , where r is the radial distance from optical axis 90. (Other conditions may require an exponent of r other than 2). The required refractive index
10 gradient in a solid polymeric cylinder can therefore be achieved by radial diffusion into the cylinder of a diluent having a refractive index different from that of the polymer. A
15 detailed consideration of suitable polymer and diluent materials is presented hereinafter. Preferably the gradient is maintainable for times quite long compared to the time of use
20 of the element, i.e. potentially perhaps for several decades; however, it may be maintainable for much shorter times, of the order of from 1—2 days up to a period of months. Such a system has the obvious advantage of
25 not requiring a significant amount of energy to maintain the gradient.

Referring now to Figure 3, there is illustrated a second embodiment of the invention wherein the polymeric matrix is in the form of an annulus 22 concentric with a rod 19. The diluent
30 20 is diffused into the matrix from the hollow space 21 formed between the rod and annulus. After diffusion, incident light impinging on the optical surface 18 is subjected to focussing action by the gradient of refractive index
35 formed in the matrix. Figure 3-A is similar in construction to Figure 3, except that the positions of the diluent and matrix have been reversed. In Figure 3-A the diluent is diffused from an external source 42 and an internal
40 hollow core 43, as indicated by the arrows 40, into an annular polymeric matrix 41.

In principle, at least four ways of achieving the radial variation in refractive index in a cylindrical symmetrical plastics element exist, i.e. two methods for positive and two methods for negative lens systems. For a positive lens system, the refractive index must decrease in the outward radial direction. Referring now to Figure 4, this can be achieved by inward
45 diffusion (indicated by the arrows 25) of an external diluent 23 having a refractive index lower than that of the matrix 24, or alternatively by the outward diffusion of a diluent of higher refractive index from a finite but small central
50 core within the polymeric matrix, as illustrated above in Figure 1. The same geometries for diffusion can also be applied to the divergent lens, i.e. the negative lens, with the relative magnitude of the refractive indices of the diluent and the polymeric matrix interchanged.

Up to this point, the cylindrically symmetrical case has been the only one considered. From a technological as well as from a fabrication standpoint, the planar symmetrical lens-like medium appears to be another useful

medium. Referring now to Figure 5, an example of the planar symmetrical case is that generated in a thick sheet 29 of a polymeric matrix by diffusion of diluent (not shown in Figure 5 or 6) either inward in the direction of the arrows 34 through the surfaces 26 and 27 toward the centre, or alternatively, as illustrated in Figure 6, outward from a central cavity 28 in the direction of the arrows 35 toward the exterior surfaces 30 and 36 of the two thick sheets 32 and 33. Such an element has the proper refractive index gradient, but now in only one direction, with planar symmetry. Thus, there is obtained the analogue of the action of the conventional glass lens which is commonly called a "cylindrical lens". That is incident light rays (not shown) to the optical surfaces 31 of the sheets would be focussed, bent or deflected into a plane rather than to a point. Advantageously, such a sheet may be shaped as a rectangular hexahedron. In the planar elements shown in Figures 5 and 6, the optical axis 37 can be considered to be an optical plane extending through the optical surfaces 31.

In addition to forming individual lenses as described hereinabove, another embodiment of the invention contemplates the use of a continuous series of such optical plastics elements to form a lightguiding or waveguiding system. Examples of such systems are illustrated in Figures 7 and 8.

Figure 7 illustrates a continuous series of negative and positive planar symmetrical lenses 38 and 39, respectively, in accordance with the present invention which, for example, may be utilized in solid-state devices as an input waveguide medium in cases in which only focussing in a plane is required. Such a waveguide system could be directly applied to a substrate and could provide a waveguide for a particular type of input signal. This is shown in Figure 8 where a waveguide 45 has been applied to a substrate 46.

Figure 9 illustrates an element in accordance with the invention having triangular optical surfaces 80 and 81 and optical axes 82 and 83 passing through the mid-points of two cavities 84 and 85. The diluent 86 and 87 will diffuse into the matrix 88 to form two distinct gradients in refractive index within the matrix. The optical axes 82 and 83 in effect pass through two separate centres of curvature contained on the surface 80 and two centres of curvature contained on the surface 81 of the element. That is, first, since 80 and 81 are flat surfaces, they may be considered to be portions of spheres of infinite radii; next, since there are two optical axes 82 and 83 passing through each of the surfaces 80 and 81, it may be considered that each of the surfaces 80 and 81 consists of two separate smaller surfaces joined together to form a single larger surface wherein each of said smaller surfaces actually represents surface portions of two separate spheres of infinite

radii. Accordingly, each optical axis, i.e. axis 82 and 83, may be considered to pass through a centre of curvature contained on surface 80 or 81. The diluents may be the same or different materials. The matrix 88 of the element may be held in place by various types of support apparatus not shown. For example, transparent glass or plastic plates may be clamped against the optical surfaces 80 and 81, or the entire element shown in Figure 9 may be encased in a poly(tetrafluoroethylene) cell assembly having glass end plates as described in the accompanying examples.

Figure 10 illustrates in cross-section a further capability of an optical element in accordance with the invention, namely its use in a reflecting medium such as a mirror. In Figure 10, a cylindrical element 100 such as that illustrated in Figure 2 is backed by reflective backing layer 101. Accordingly, when an object is placed in the field of view of such an element, a reflected image thereof may be obtained. The optical appearance of the reflected image in comparison to the original object will depend on the type of lens action possessed by the element 100. For example, the image may be larger, smaller or inverted.

Many varied types of lenses can be derived from optical elements such as described with reference to the drawings, by applying conventional lens-making technology thereto. Moulding and/or grinding methods, for example, can be used to make many types of thin and thick lenses and lens systems, including convergent and divergent spherical and cylindrical lenses.

A primary advantage of the present invention is that the plastics lens elements of the invention possess lens properties, i.e. a continuous gradient in refractive index, without any curvature of the optical surfaces being necessary. Conventional lens-making techniques applied to such elements make it possible to obtain a curved-surface lens having a refractive index gradient which is either difficult to achieve, or incapable of being achieved, solely by conventional lens-making techniques.

With respect to appropriate polymeric materials useful in the practice of the present invention, as noted hereinabove these polymeric materials should be substantially amorphous and transparent. In addition, it is preferred that these materials exist in the glassy state at room temperature. By the term amorphous polymer is simply meant the conventional definition of such a polymeric material, namely that the molecular structure thereof exists in an irregular pattern; in other words, the molecular structure thereof is substantially noncrystalline. Since polymeric materials having a substantially crystalline molecular structure can exhibit a high degree of light scattering, it should be apparent that this property would generally render such materials useless as light transmission media.

Glassy state polymeric materials are generally characterized by a large Young's modulus, of the order of 10^{10} to 10^{11} dynes/cm². The properties of amorphous polymeric materials existing in the glassy state are well known in the art and can be further explored in numerous published material on the subject. For example, see Meares, P., *Polymers: Structure and Bulk Properties*, Van Nostrand Company Limited, London (1965) Chapter 9.

Preferably, the useful glassy amorphous polymeric materials selected in the present invention also exhibit a relatively high glass transition temperature, T_g . The glass transition temperature of the polymeric material is the temperature at which the material undergoes a transition from the glassy state to the retarded highly elastic or leathery state. Materials having a glass transition temperature greater than 27°C. may be used in the present invention, with preferred materials having a glass transition temperature greater than 70°C. Although materials having a lower glass transition temperature may be used, such materials are generally not preferred, as a plastics element prepared from such a material has a gradient of refractive index which is generally not stable at room temperature, and such an element may not possess sufficient rigidity to maintain its shape at room temperature.

The polymeric materials useful in the practice of the present invention are further characterized by having a refractive index of the order of 1.5, usually within the range of from 1.42 to 1.79. Moreover, the polymeric materials preferred in most embodiments of the present invention have a low dispersion index (V), which is defined as

$$V = \frac{n_D - 1}{n_F - n_C}$$

where n_D represents the sodium D line, n_F represents the hydrogen F line, and n_C represents the hydrogen C line. Generally, polymeric materials useful in the present invention have a dispersion index within the range of from 35 to 50. However, in certain cases it may be useful to utilize a polymeric material having a substantially higher dispersion index, within the range of from 50 to 60.

The polymeric materials utilized to form the matrix should also be transparent and preferably clear i.e. colourless, although in certain applications a tinted transparent element may be desired.

A partial listing of refractive indices and dispersion indices of some typical resins and polymeric materials may be found in Table I hereinbelow.

TABLE I
Refractive Indices of Resins and Polymers

Refractive index	Reciprocal dispersive power	Material
1.356	—	Poly(1,1-dihydroperfluoro- hexyl acrylate)
1.367	—	Poly(1,1-dihydroperfluoro- butyl acrylate)
1.39—1.43	—	Poly(chlorotrifluoroethylene)
1.394 (20°C.)	—	
1.4177 (20°)	65.3	Poly(trifluoroisopropyl methacrylate)
1.436 (20°C)	53	Poly(triethoxy silicol methacrylate)
1.452	—	Poly(vinyl isobutyl ether)
1.454	—	Poly(vinyl ethyl ether)
1.4563 (30°)	—	Poly(ethylene glycol)
1.46—1.50	—	Cellulose acetate butyrate
1.494 (21°C)	—	
1.46—1.50	—	Cellulose acetate
1.4634 (25°)	—	Poly(butyl acrylate)
1.4638 (20°)	51	Poly(tert.-butyl methacrylate)
1.467 (20°)	—	Poly(vinyl methyl ether)
1.4685 (20°)	58	Poly(ethyl acrylate)
1.47—1.49	—	Poly(vinyl acetate)
1.4667 (24°)	—	
1.47—1.49	—	Poly(vinyl butyral)
1.47—1.48	—	Cellulose propionate
1.479 (21°)	—	Ethylcellulose
1.47	—	Cellulose acetate propionate
1.47—1.52	—	Benzylcellulose
1.4725 (20°)	59	Poly(methyl acrylate)
1.480 (25°)	—	
1.4728 (20°)	57.9	Poly(isopropyl methacrylate)
1.4744 (25°)	—	Poly(glycol succinate)
1.4757 (20°)	55	Poly(vinyl formate)
1.477 (25°)	65.6	Poly(isobutyl methacrylate)
1.4768	57.8	Poly(monofluoroethyl meth- acrylate)
1.48—1.50	—	Poly(vinyl acetal)
1.4813 (20°)	57	Poly(n-hexyl methacrylate)
1.483—1.485 (25°)	—	Poly(ethyl methacrylate)
1.4831 (25°)	49	Poly(n-butyl methacrylate)
1.4831 (20°)	52.9	Poly(ethylidene dimeth- acrylate)
1.4833 (20°)	32.0	Poly(β-ethoxyethyl meth- acrylate)
1.4840 (25°C)	—	Poly(glycol maleate)
1.484 (25°)	—	Poly(n-propyl methacrylate)
1.485 (20°)	54	Poly-(3,3,5-trimethylcyclo- hexyl methacrylate)
1.485—1.49	—	Poly(methyl methacrylate)
1.4893 (23°)	57.6	
1.490 (20°)	56.3	
1.4855 (20°)	50	Poly(diacetin methacrylate)
1.4868 (20°)	48	Poly(-2-nitro-2-methylpropyl methacrylate)

TABLE I (Continued)

Refractive index	Reciprocal dispersive power	Material
1.4889 (20°)	57	Poly(triethylcarbiny methacrylate)
1.49	—	Poly(propylene)
1.49—1.53	—	Poly(vinyl alcohol) moulding compound)
1.4903 (20°C)	55	Poly(ethyl glycolate meth- acrylate)
1.4917 (20°)	49	Poly(α -methallyl methacrylate)
1.494	—	Poly(methyl methacrylate 80%, methacrylic formic anhydride 20%)
1.4947 (20°)	55	Poly(-3-methylcyclohexyl methacrylate)
1.496 $\pm$ 0.003 (21—23°)	—	Rosin ester
1.4969 (20°)	58	Poly(cyclohexyl α -ethoxy- acetate)
1.4975 (20°)	—	Poly(-4-methylcyclohexyl methacrylate)
1.4990 (20°)	56.3	Poly(decamethylene glycol dimethacrylate)
1.50—1.514	—	Cellulose nitrate
1.501 (21°)	—	Allyl cast resin
1.50—1.575	—	Phenol-formaldehyde resin
1.5—1.7	—	Poly(-sec.-butyl α -chloro- acrylate)
1.500 $\pm$ 0.001 (25°)	—	Poly(diallyl glycol carbonate)
1.5001 (20°)	58.8	
1.50131 (20°)	—	
1.51002 (20°)	—	
1.502 $\pm$ 0.001 (25°)	—	Poly (ethyl α -chloroacrylate)
1.5028 (20°)	53	Poly(2-methylcyclohexyl methacrylate)
1.5048 (23°)	56.0	Poly(hexamethylene glycol dimethacrylate)
1.5066 (20°)	56	
1.505—1.51	—	Poly(isobutylene)
1.5059 (20°)	54.6	Poly(bornyl methacrylate)
1.5063 (20°)	53.4	Poly(ethylene dimethacrylate)
1.5066 (20°)	56.2	Poly(cyclohexyl methacrylate)
1.5099 (23°)	54.4	
1.5067 (20°)	54.3	Poly(cyclohexanediol-1,4- dimethacrylate)
1.508	—	Butyl rubber, unvulcanized
1.508	47	Poly(- β -methallyl methacrylate)
1.5110 (20°)	—	
1.5096 (20°)	54	Poly(tetrahydrofurfuryl methacrylate)
1.51—1.55	—	Poly(vinyl acetate) medium acetate type
1.5111 (20°)	54	Poly(1-methylcyclohexyl methacrylate)
1.5117 (20°)	—	Poly(pentaerythritol tetra- methacrylate)

TABLE I (Continued)

Refractive index	Reciprocal dispersive power	Material
1.5118 (20°)	53.9	Poly(methyl- α -methylene butyrolactone)
1.51—1.52		
1.512 (25°)	—	Poly(vinyl chloroacetate)
1.5129 (20°)	46	Poly(vinyl methacrylate)
1.514 (25°)	—	Poly(ethylene glycol fumarate)
1.514 (20°)	50	Poly(terpineyl methacrylate)
1.517 (20°)	54	Poly(ethylene chlorohydrin methacrylate)
1.5172 (20°)	57	Poly(methyl- α -chloroacrylate)
1.5155		
1.52480		
1.5174 (20°)	54	Poly(diethylaminoethyl methacrylate)
1.5179 (20°)	56	Poly(2-chlorocyclohexyl methacrylate)
1.519 (25°)	—	Natural rubber
1.5196 (20°)	49	Poly(allyl methacrylate)
1.52	—	Poly(acrylonitrile)
1.52	—	Poly(methacrylonitrile)
1.52	—	Poly(butadiene)
1.52	—	Butadiene-acrylonitrile copolymers
1.5200 (20°)	54.5	Poly(methyl isoprenyl ketone)
1.5219 (20°)	—	Isoprene (polymer)
1.5228(20°)	48.5	Poly(methacrylic anhydride)
1.523—1.57	—	Polyester cast resin, rigid
1.5246 (20°)	53	Poly(-N- β -methoxyethyl methacrylamide)
1.525—1.529 (21°)	—	Poly(vinyl chloride-acetate)
1.5250 (20°)	53	Polycyclohexyl-cyclohexyl methacrylate
1.525 (20°)	—	Poly(2,3-dimethylbutadiene)
1.527 (25°)	—	Poly(acrylic acid)
1.529	—	Poly(acrolein)
1.53	—	Poly(vinylpyrrolidone)
1.53	—	Hydrochlorinated rubber
1.53—1.55	—	Nylon moulding compound
1.5303 (20°)	56.4	Poly(vinyl cyclohexene dioxide)
1.532 $\pm$ 0.001 (25°)	—	Poly(cyclohexyl α -chloroacrylate)
1.533 $\pm$ 0.001 (25°)	—	Poly(β -chloroethyl chloroacrylate)
1.536 (25°)	—	Poly(vinyl chloride-acetate) (95/5)
1.537 (20°)	52.5	Poly(β -aminoethyl methacrylate)
1.5381 (20°)	39.2	Poly(furfuryl methacrylate)
1.5390 (20°)	41.8	Poly(butyl mercaptyl methacrylate)
1.5396 (20°)	40	Poly(α -phenyl-n-amyl methacrylate)

TABLE I (Continued)

Refractive index	Reciprocal dispersive power	Material
1.5398 (20°)	47.5	Poly (N-methyl methacryl- amide)
1.54	—	Cellulose acetate (partly saponified)
1.54—1.56	—	Poly(vinyl chloride)
1.565 (40°)	—	Urea-formaldehyde moulding compound
1.54—1.56	—	Poly(glycerol rosin-maleate)
1.541 (25°)	—	Poly(β -bromoethyl methacrylate)
1.5426 (20°)	40	Poly(vinyl-vinylidene chloride)
1.543	—	(6/94)
1.5431 (20°)	47.8	Poly(methylene- α -valerolactone)
1.544—1.546 (25°)	—	Kauri copal
1.545—1.555 (25°)	—	Poly(vinyl acetate) (low acetate type)
1.545 $\pm$ 0.003 (20°)	—	Poly(abietic acid)
1.546 (25°)	—	Poly(ethyl sulphide meth- acrylate)
1.547 (20°)	44	Poly(cyclohexyl bromoacrylate)
1.547 $\pm$ 0.001 (25°)	—	Poly(N-allylmethacrylamide)
1.5476 (20°)	47	Poly(α -phenylethyl meth- acrylate)
1.5487 (20°)	37.5	Poly(vinylfuran)
1.55 (20°)	—	Poly(p-methoxybenzyl meth- acrylate)
1.552 (20°)	32.5	Poly(-p-isopropylstyrene)
1.554 (20°)	35	μ -Poly(chloroprene)
1.5540 (20°)	36	Poly(ethylene glycol benzoate methacrylate)
1.555 (20°)	36.8	Poly(-p,p'-xylylenyl di- methacrylate)
1.5559 (20°)	37	Rosin modified glycerol-phthalate
1.557 (25°)	—	Poly(α -phenylallyl methacrylate)
1.5573 (20°)	34.8	Poly(-p-cyclohexylphenyl methacrylate)
1.5575 (20°)	39.0	Poly(- β -phenylethyl meth- acrylate)
1.5592 (20°)	36.5	Poly(- α -(o-chlorophenyl) ethyl methacrylate)
1.5624 (20°)	37.5	Poly(phenyl Cellosolve methacrylate)
1.5625 (20°)	36.2	Maleic anhydride-styrene copolymer
1.564 (21°)	—	Poly(-1-phenylcyclohexyl methacrylate)
1.5645 (20°)	40	Poly(methyl α -bromoacrylate)
1.5672 (20°)	46.5	Poly(benzyl methacrylate)
1.5680 (20°)	36.5	Poly(β -phenylsulphone)
1.5682 (20°)	39	ethyl methacrylate)
1.5683 (20°)	36.8	Poly(-m-cresyl methacrylate)
1.57	—	Acrylonitrile-styrene copolymer
1.57 (20°)	30	Polydiallyl cinnamate
1.570 $\pm$ 0.003 (20—22°)	—	Poly(ethylene glycol phthalate)
1.5705 (20°)	33.4	Poly(o-methoxyphenyl methacrylate)

TABLE I (Continued)

Refractive index	Reciprocal dispersive Power	Material
1.5706	35	Poly(phenyl methacrylate)
1.5707 (20°)	34	Poly(methacryl methyl salicylate)
1.5707 (20°)	—	Poly(o-cresyl methacrylate)
1.571—1.572 (20°)	—	Poly(diallyl phthalate)
1.5714 (20°)	33	Poly(eugenol methacrylate)
1.5739 (20°)	44	Poly(-2,3-dibromopropyl methacrylate)
1.575 ± 0.003 (20°)	—	Poly(glycerol phthalate)
1.5775 (20°)	30.7	Poly(vinyl benzoate)
1.5823 (20°)	37	Poly(o-chlorobenzyl meth- acrylate)
1.584 ± 0.003 (20°)	—	Poly(pentaerythritol phthalate)
1.5845 (20°)	27.4	Poly(m-nitrobenzyl meth- acrylate)
1.5857 (20°)	37	Poly(N-β-phenylethylmeth- acrylamide)
1.59—1.60	30.8	Polystyrene
1.5901 (25°)	—	
1.5858	—	
1.5932 (20°)	29.7	Poly(-o-methoxystyrene)
1.5951 (20°)	26.5	Poly(cinnamyl methacrylate)
1.5933 (20°)	31.0	Poly(benzhydryl methacrylate)
1.5964 (20°)	33	Poly(-p-bromophenyl meth- acrylate)
1.5965 (20°)	34.5	Poly(-N-benzylmethacrylamide)
1.5967 (20°)	28	Poly(-p-methoxystyrene)
1.60—1.63	—	Poly(vinylidene chloride)
1.60—1.70	—	Polysulphide (Thiokol)
1.6006 (20°)	36	Poly(methacryl phenyl salicylate)
1.6040 (20°)	30	Poly(-o-chlorobenzhydryl methacrylate)
1.6056	—	Polycarbonate from 3,3',5,5'- tetrachlorodiphenyl
1.608 (20°)	22.5	Poly(pontachlorophenyl methacrylate)
1.6098	21	Poly(-o-chlorostyrene)
1.612 ± 0.001 (25°)	—	Poly(phenyl α-bromoacrylate)
1.6150 (20°)	28.1	Poly(-p-divinylbenzene)
1.617—1.66	—	Coumarone-indene resins
1.6200 (20°)	24.1	Poly(-N-vinylphthalimide)
1.62—1.64	—	Poly(dichlorostyrene)
1.6248 (20°)	31.3	Poly(-2,6-dichlorostyrene)
1.6298 (20°)	24	Poly(-β-naphthyl methacrylate)
1.63	25	Poly(-α-naphthylcarbonyl methacrylate)
1.6319 (23°)	23.1	Poly(fluorenyl methacrylate)
1.6376 (20°)	29	Poly(vinyl thiophene)
1.64—1.70	—	Poly(-α-naphthyl methacrylate)
1.6411 (20°)	20.5	
1.645 (20°)	28	Poly(lead dimethacrylate)
1.645 ± 0.003 (20°)	—	Cresylic acid-formaldehyde condensation resin

TABLE I (Continued)

Refractive index	Reciprocal dispersive power	Material
1.650 (25°)	—	Accroides
1.6568 (20°)	27.5	Poly(vinyl phenyl sulphide)
1.66	—	Butylphenol-formaldehyde resin
1.6818 (20°)	20.9	Poly(vinylnaphthalene)
1.683 (20°)	18.8	Poly(vinylcarbazole)
1.70	—	Phenol-formaldehyde resin

- Other polymeric materials useful for preparing the lens-like media of the present invention are the polymeric compounds comprising a thio-substituted bicyclic [2.2.1] moiety disclosed in our copending British Patent Application No. 56796/70 (Serial No. 1,330,520), and the polymeric compounds disclosed in our copending British Patent Application No. 56794/70 (Serial No. 1,332,195).
- The materials utilized as diluents in the present invention may be selected from a wide variety of organic materials. In view of the variety of materials which may comprise these diluent materials, it is helpful to characterize various materials useful as diluents by reference to certain advantageous properties which such materials should possess. The organic diluent materials may be characterized as transparent materials; furthermore, the diluent should possess an index of refraction different from that of the polymeric matrix material; and, in addition, the diluent should be incapable of inducing crystallization of the polymeric matrix material. The diluents, as noted hereinbefore, are capable of diffusing into the polymeric matrix material used in the invention. A complete understanding of the diluent-polymeric matrix interaction occurring during diffusion is not presently available. However, it may be noted that preferred diluents used in the present invention are solvents for the polymeric matrix material.
- As will be apparent from the properties which the diluents should advantageously possess, a particular diluent selected for use in the invention will vary depending on the particular glassy amorphous polymeric material used for the matrix of the element. For example, a material which is a solvent for one particular glassy amorphous polymeric matrix and which possesses an index of refraction different from that of this particular polymeric matrix material and which is incapable of inducing crystallization with this same particular polymeric matrix material may not be a satisfactory diluent material for a different glassy amorphous polymeric matrix material. Accordingly, the use of a particular diluent, as stated hereinabove, depends upon the selection of the glassy amorphous polymeric matrix material.
- In addition to the properties noted hereinabove, diluents are preferably of low molecular weight in comparison to the molecular weight of the polymeric matrix materials. Generally, useful diluents have a molecular weight less than 1000. Preferred diluents generally have a molecular weight range of the order of 30—400. The reason for using relatively low molecular weight materials is to enhance the diffusion of the diluent into the polymeric matrix material. That is, to obtain an appropriate diffusion profile in a polymeric matrix within a reasonable time interval, a diffusing diluent molecule should be relatively small in comparison to the molecules of the polymeric matrix material into which it is diffusing.
- Table II contains a partial listing of various organic materials which may be utilized, depending upon the particular polymeric matrix material, as diluents in the practice of the present invention.

TABLE II

Diluent	Refractive Index	Boiling Point (°C)
ethyl isocyanide	1.3659	79
isobutyraldehyde	1.37302	61.5
methyl ethyl ketone	1.38071	79.6
butyronitrile	1.3816	118
methyl methacrylate	1.413	100
isobutyl methacrylate	1.418	155
γ -chloronaphthalene	1.63321	263
γ -bromonaphthalene	1.65876	281.1
tripropylboron	1.42354	156
1-nitropropane	1.40027	132
2-nitropropane	1.3941	120
ethyl propionate	1.38385	99.10
n-butyl cyanide	1.3909	141
octane	1.3975	125.8
1-ethylaminonaphthalene	1.6477	305
1-isonaphthalene	1.705	305
dimethyl sulphate	1.3874	188
methanol	1.33118	64.6
ethylene formate	1.358	174
2-fluoroethanol	1.3647	103.3
heptane	1.3876	98.4
1-octanol	1.429	195
2-octanol	1.426	178.5
2-octanone	1.416	173.5
ethylene diacetate	1.415	186
di-n-butyl phthalate	1.4925	340
dimethyl phthalate	1.5155	280

When a transparent element in accordance with the present invention is provided with a reflective backing layer to provide an element having mirror-like action as well as lens-like action, it will be appreciated that any of the known types of reflecting backing materials and compositions may be used. Thus, various reflective metallic backing layers such as silver or aluminium may be used. Nonmetallic reflective layers may also be used. The reflective backing may be applied directly to the transparent element or applied to a support which is immediately adjacent the element or a spaced distance therefrom. The reflective backing should be positioned adjacent the transparent element and the optical axis of the element should pass through the reflective backing.

With respect to the diffusion operation utilized in the process of the present invention to prepare the plastic elements of the present invention, it has been found useful to diffuse the diluent into the polymeric matrix material at temperatures generally higher than the glass transition temperature, T_g , of the polymer-diluent system. An additional factor affecting the diffusion temperatures utilized in the process of the present invention is the boiling point of the diluent. That is, in the process of the invention the diluent is advantageously diffused into the polymeric matrix from a liquid state. For this reason, the diffusion temperature should be lower than the boiling point of the diluent to avoid vapourization thereof. Although the diluent is also capable of diffusing into the polymeric matrix when the diluent is in a vapour or gaseous state, it presently appears advantageous to effect diffusion of a diluent which is primarily in the liquid state.

It will be observed that the glass transition temperature, T_g , for the polymer-diluent system is different from the glass transition temperature of the polymer by itself. Moreover, the glass transition temperature of the polymer-diluent system will continually change as the concentration of diluent in the polymeric matrix increases. In the usual case, the glass transition temperature of the polymer-diluent system is lower than that of the polymer alone.

Generally, in the diffusion process of the present invention it has been found useful to select a diffusion temperature which is from 2°C to 25°C. below the glass transition temperature of the polymer alone. Using these preferred diffusion temperatures, diffusion coefficients of the order of about 10^{-6} cm²/sec. have been commonly observed in the process of the present invention. With this type of diffusion coefficient, diffusion of the diluent into a polymeric matrix material to a depth of about 1 centimetre is generally easily achieved in times ranging from several hours to several days, depending upon the particular diluent and particular polymeric matrix under consideration. Since the refractive index gradient

existing in the plastics elements of the present invention is directly dependent on the concentration profile of the diluent in the polymeric matrix material, by changing or programming the particular temperatures used during the diffusing process one can vary the resulting concentration profile of the diluent in the polymeric matrix material and thus influence the final refractive index gradient obtained.

For additional information respecting the general theoretical nature of diffusion processes, reference may be had to the following publications: 'Diffusion in Polymers' edited by J. Crank and G. S. Park, Academic Press, London and New York (1968); and H. Fujita, "Diffusion In Polymer-Diluent Systems"; Fortschr. Hochpolym.-Forsch., Vol. 3, page 1, (1961).

Although the amount of diluent used in the process of the present invention to achieve a particular lens-like element will vary depending upon the difference in refractive index existing between the diluent and the polymeric material, and depending upon the particular diffusion properties which exist with respect to a particular diluent-polymer system, a generally useful concentration of diluent lies within the range of from 2 to 40 weight % of diluent, based on the total weight of the resultant polymer-diluent system.

During the diffusion process used in the present invention to form a gradient of refractive index in the polymeric matrix, it should be noted that diffusion of the diluent into the polymeric matrix actually involves mutual diffusion. Since, however, the diluent diffuses into the polymeric matrix more readily than the polymeric matrix diffuses into the diluent (due primarily to the difference in size between the diluent molecule and polymeric matrix molecules) it is convenient to speak of the diluent diffusing into the polymeric matrix. However, when the present specification and claims refer to the diffusion of the diluent into the polymeric matrix, the diffusion of the polymeric matrix into the diluent is included, as well as the diffusion of the diluent into the matrix.

In carrying out the diffusion process, various types of apparatus may be employed. The particular apparatus utilized is not deemed critical to the present invention, but convenient equipment which may be used is briefly described in the following examples.

It may be observed that when an element of the present invention is formed within, for example, a cell assembly apparatus similar to that described in the accompanying examples, wherein transparent end windows are clamped over the end surfaces of the polymeric matrix during the diffusion process, it may be unnecessary to remove the cell assembly upon completion of the diffusion process. Since the end surfaces of the polymeric matrix which are to receive incident electromagnetic radiation

are covered by transparent windows, visible light can readily enter and leave the plastic element through these transparent windows of the cell assembly.

5 In many cases it may in fact be desirable to retain the plastics element of the present invention firmly clamped in place within the cell assembly. For example, if a plastics
10 element such as those illustrated in Figs. 1, 3, 3A, 6 and 9 is prepared, wherein the plastics element has a hollow inner core or cavity from which the liquid diluent is diffused into the polymeric matrix of the element, it may be
15 desirable to retain the resultant element in the cell assembly to prevent any residual diluent which has not completely diffused into the polymeric matrix from running out of the inner core. In addition, the cell assembly or other similar apparatus may give additional
20 support to the plastics elements of the invention.

Of course if, as is often the case, the diffusion process is sufficiently complete for the diluent and polymeric matrix to have undergone marked diffusion into one another, the resultant
25 element may be freely removed from the cell assembly as there will be little or no remaining liquid diluent in the core which can run out. Following diffusion of the diluent and polymeric matrix, the original inner core will be observed
30 to have been substantially reduced in size and in place thereof will be formed a solid composition comprising a mixture of the polymeric matrix and diluent. Depending upon the extent of the diffusion of the polymeric
35 matrix into the diluent, the original cavity will be partially or wholly filled in with this solid mixture of polymeric matrix and diluent.

Various embodiments of the present invention are illustrated in the following examples.

40 Example 1. A cylindrically symmetrical element with positive lens-like action was made.

A rod of poly(methyl methacrylate), 2 inches long and half an inch in diameter and
45 having flat polished ends, was placed in a holder consisting of an outer concentric cylinder of poly(tetrafluoroethylene) of about the same length. The holder had a wall thickness of an eighth of an inch and an inner diameter of 1
50 inch, and its ends were capped with plate glass windows a quarter of an inch thick and one and a quarter inches in diameter. The glass end windows were held clamped by annular one sixteenth of an inch thick steel washers of
55 1 inch inside and 2 inch outside diameter, joined by screws parallel to the cylinder and rod axes.

The diffusing liquid diluent was added through a side hole in the poly(tetrafluoroethylene) cylinder, which was then capped by a metal screw. The diluent liquid used in this
60 example was ethylene diacetate.

The cell assembly was placed with the rod axis vertical in an oven at 95°C. for 40 hours,
after which the oven was turned off and was
65 allowed to reach room temperature. The cell assembly was subsequently removed from the oven and tested for lens-like action, several examples of which follow.

When placed in a parallel He-Ne laser beam of 1mm. diameter with the beam passing down the cell axis normal to the end plates, focussing of the light occurred. A focal length of about
70 2.6 inches was observed. A laser beam a quarter of an inch in diameter consisting of parallel rays of light was passed normal to the end plates, and the beam was focussed with about the same focal length.

When the cell was placed on a page of printed text with the page rotated 180° (in its plane) from the erect position, a magnified
80 image of the text was observed. As the cell was raised, the image broke up into two circular groups of concentric closed loops. At a distance of about one inch from the bottom of the cell
85 to the page, an erect image of the text appeared across the centre of the cell.

Example 2.

A cylindrically symmetrical element with positive lens-like action was made.

A rod of poly(methyl methacrylate) three quarters of an inch in diameter and 2 inches long was placed in a cell similar to that described in Example 1. Ethylene diacetate was added and the cell assembly was heated at
95 95°C. for 12 days.

The cell was observed to give lens-like action when placed in a collimated laser beam.

Example 3.

A half inch diameter rod of poly(methyl methacrylate), 2 inches long, was placed in a cell similar to that described in Example 1. A hollow poly(methyl methacrylate) cylinder 2 inches long, having an outside diameter of 1 inch and an inside diameter of three quarters of an inch was placed in the cell around the smaller diameter rod. The gap between the rod and the poly(methyl methacrylate) cylinder was filled with ethylene diacetate (via the cell end) and the cell assembly was placed in an oven at 95°C. for 11 days. After this time, the central rod could no longer be distinguished.

When placed in a parallel beam of a He-Ne laser, lens-like focussing action was observed with a strong central spot of light which persisted for some distance beyond the initial focal point. The far-field image was a ring of light, suggesting that the cell assembly had annular lens-like properties.

Example 4.

A cylindrically symmetrical element with positive lens-like action was made.

A rod of polystyrene, 2 inches long and half an inch in diameter and having flat polished ends, was placed in a cell similar to that of Example 1 except that the holder had an inner diameter of three quarters of an inch.

The diffusing liquid diluent was added through a side hole in the poly(tetrafluoroethylene) cylinder, which was then capped by a metal screw. The diluent liquid used in this example was dimethyl phthalate.

The cell assembly was placed with the rod axis vertical in an oven at 94°C for 63 hours, after which the oven was turned off and was allowed to reach room temperature. The cell assembly was subsequently removed from the oven and tested for lens-like action, several examples of which follow.

When placed in a parallel He-Ne laser beam of 1 mm diameter with the beam passing down the cell axis normal to the end plates, focussing of the light occurred. Focussing to a point just inside or outside of the cell end was observed. When the cell was placed on a page of printed text with the page rotated 180° (in its plane) from the erect position, a magnified image of the text was observed. As the cell was raised, the image size decreased. An inverted image of distant objects was observed when viewed through the centre of the lens.

Example 5.

A cylindrically symmetrical element with positive lens-like action was made.

A rod of polystyrene half an inch in diameter and a quarter of an inch long was placed in a cell similar to that described in Example 1, except that the cell length was about a quarter of an inch. Di-n-butyl phthalate was added and the cell assembly was heated at 95°C. for 47 hours.

The cell was observed to give lens-like action when placed in a collimated laser beam.

Example 6.

A planar symmetrical element with lens-like action was made.

A strip of poly(methyl methacrylate) 2 inches long, half an inch wide and a quarter of an inch thick, having flat polished ends, was centrally placed in a holder consisting of an outer cylinder of poly(tetrafluoroethylene) of about the same length, with a square hole half an inch by half an inch. The ends of the holder were capped with quarter inch thick plate glass windows one and a quarter inches in diameter. The glass end windows were held clamped by annular one sixteenth of an inch thick steel washers of 1 inch inside and 2 inch outside diameter, joined by screws parallel to the cylinder and rod axes.

The diffusing liquid diluent was added through side holes in the poly(tetrafluoroethylene) cylinder, which were then capped by

metal screws. The diluent liquid used in this example was ethylene diacetate.

The cell assembly was placed with the rod axis vertical in an oven at 90°C. for 20 hours, after which the oven was turned off and was allowed to reach room temperature. The cell assembly was subsequently removed from the oven and tested for lens-like action.

The cell was then returned to the oven, heated at 90°C. for another 26 hours, again removed, cooled and tested for lens-like action.

When placed in a parallel He-Ne laser beam of 1 mm diameter with the beam passing down the cell axis normal to the end plates, focussing of the light to a line occurred. The cell gave stronger lens action after 20 hours than after 46 hours, suggesting that the shorter diffusion time led to a better lens material.

Example 7.

A cylindrically symmetrical element with positive lens-like action was made.

A rod of poly(methyl methacrylate) half an inch in diameter and a quarter of an inch long, was placed in a cell similar to that described in Example 5. Ethylene diacetate was added and the cell assembly was heated at 95°C for 43 hours.

The cell was observed to give lens-like action when placed in a collimated laser beam.

Example 8.

A cylindrically symmetrical element with positive thick mirror-like action was made.

A rod of poly(methyl methacrylate) 2 inches long and half an inch in diameter and having flat, polished ends was placed in a cell similar to that of Example 1. One of the glass end plates had a coating of aluminium of about 80% reflectivity on the surface in contact with the poly(methyl methacrylate) rod.

The diffusing liquid diluent was added through a side hole in the poly(tetrafluoroethylene) cylinder, which was then capped by a metal screw. The diluent liquid used in this example was ethylene diacetate.

The cell assembly was placed with the rod axis vertical in an oven at 95°C. for 47 hours, after which the oven was turned off and was allowed to reach room temperature. The cell assembly was subsequently removed from the oven and tested for mirror-like action. In looking into the cell assembly, an observer saw an inverted smaller image of part of his face, indicating a positive mirror-like action, the object being outside the focal length.

WHAT WE CLAIM IS:—

1. A transparent element for the deflection of incident electromagnetic radiation, comprising a shaped transparent polymeric matrix of a homogeneous glassy amorphous polymer and a transparent diluent within the matrix

5 A rod of polystyrene, 2 inches long and half an inch in diameter and having flat polished ends, was placed in a cell similar to that of Example 1 except that the holder had an inner diameter of three quarters of an inch.

10 The diffusing liquid diluent was added through a side hole in the poly(tetrafluoroethylene) cylinder, which was then capped by a metal screw. The diluent liquid used in this example was dimethyl phthalate.

15 The cell assembly was placed with the rod axis vertical in an oven at 94°C for 63 hours, after which the oven was turned off and was allowed to reach room temperature. The cell assembly was subsequently removed from the oven and tested for lens-like action, several examples of which follow.

20 When placed in a parallel He-Ne laser beam of 1 mm diameter with the beam passing down the cell axis normal to the end plates, focussing of the light occurred. Focussing to a point just inside or outside of the cell end was observed. When the cell was placed on a page of printed text with the page rotated 180° (in its plane) from the erect position, a magnified image of the text was observed. As the cell was raised, the image size decreased. An inverted image of distant objects was observed when viewed through the centre of the lens.

30 Example 5.

A cylindrically symmetrical element with positive lens-like action was made.

35 A rod of polystyrene half an inch in diameter and a quarter of an inch long was placed in a cell similar to that described in Example 1, except that the cell length was about a quarter of an inch. Di-n-butyl phthalate was added and the cell assembly was heated at 95°C. for 47 hours.

40 The cell was observed to give lens-like action when placed in a collimated laser beam.

Example 6.

A planar symmetrical element with lens-like action was made.

45 A strip of poly(methyl methacrylate) 2 inches long, half an inch wide and a quarter of an inch thick, having flat polished ends, was centrally placed in a holder consisting of an outer cylinder of poly(tetrafluoroethylene) of about the same length, with a square hole half an inch by half an inch. The ends of the holder were capped with quarter inch thick plate glass windows one and a quarter inches in diameter. The glass end windows were held clamped by annular one sixteenth of an inch thick steel washers of 1 inch inside and 2 inch outside diameter, joined by screws parallel to the cylinder and rod axes.

60 The diffusing liquid diluent was added through side holes in the poly(tetrafluoroethylene) cylinder, which were then capped by

metal screws. The diluent liquid used in this example was ethylene diacetate.

65 The cell assembly was placed with the rod axis vertical in an oven at 90°C. for 20 hours, after which the oven was turned off and was allowed to reach room temperature. The cell assembly was subsequently removed from the oven and tested for lens-like action.

70 The cell was then returned to the oven, heated at 90°C. for another 26 hours, again removed, cooled and tested for lens-like action.

75 When placed in a parallel He-Ne laser beam of 1 mm diameter with the beam passing down the cell axis normal to the end plates, focussing of the light to a line occurred. The cell gave stronger lens action after 20 hours than after 46 hours, suggesting that the shorter diffusion time led to a better lens material.

Example 7.

80 A cylindrically symmetrical element with positive lens-like action was made.

85 A rod of poly(methyl methacrylate) half an inch in diameter and a quarter of an inch long, was placed in a cell similar to that described in Example 5. Ethylene diacetate was added and the cell assembly was heated at 95°C for 43 hours.

90 The cell was observed to give lens-like action when placed in a collimated laser beam.

Example 8.

A cylindrically symmetrical element with positive thick mirror-like action was made.

95 A rod of poly(methyl methacrylate) 2 inches long and half an inch in diameter and having flat, polished ends was placed in a cell similar to that of Example 1. One of the glass end plates had a coating of aluminium of about 80% reflectivity on the surface in contact with the poly(methyl methacrylate) rod.

100 The diffusing liquid diluent was added through a side hole in the poly(tetrafluoroethylene) cylinder, which was then capped by a metal screw. The diluent liquid used in this example was ethylene diacetate.

105 The cell assembly was placed with the rod axis vertical in an oven at 95°C. for 47 hours, after which the oven was turned off and was allowed to reach room temperature. The cell assembly was subsequently removed from the oven and tested for mirror-like action. In looking into the cell assembly, an observer saw an inverted smaller image of part of his face, indicating a positive mirror-like action, the object being outside the focal length.

WHAT WE CLAIM IS:—

1. A transparent element for the deflection of incident electromagnetic radiation, comprising a shaped transparent polymeric matrix of a homogeneous glassy amorphous polymer and a transparent diluent within the matrix





- forming a continuous gradient in refractive index extending in a direction substantially perpendicular to an optical axis extending through the element, the diluent comprising an organic liquid having a molecular weight of less than 1000, which possesses an index of refraction different from that of the polymer and which is incapable of inducing crystallization of the polymer.
2. An element as claimed in Claim 1 and having two spaced optical surfaces through which the electromagnetic radiation can pass, the surfaces being substantially flat and aligned substantially parallel to one another, and the optical axis extending therebetween.
3. An element as claimed in Claim 1 or 2, wherein the polymer has a glass transition temperature greater than 27°C.
4. An element as claimed in Claim 3, wherein the polymer has a glass transition temperature greater than 70°C.
5. An element as claimed in any one of Claims 1 to 4, wherein the polymer has a refractive index of from 1.42 to 1.79.
6. An element as claimed in any one of Claims 1 to 5, wherein the polymer has a dispersion index of from 35 to 60.
7. An element as claimed in Claim 6, wherein the polymer has a dispersion index of from 35 to 50.
8. An element as claimed in Claim 6, wherein the polymer has a dispersion index between 50 and 60.
9. An element as claimed in any one of Claims 1 to 8, wherein the diluent is a solvent for the polymer.
10. An element as claimed in any one of Claims 1 to 9, wherein the diluent has a molecular weight of from 30 to 400.
11. An element as claimed in any one of Claims 1 to 10, wherein the amount of diluent is from 2 to 40 weight %, based on the total weight of polymer and diluent.
12. An element as claimed in any one of Claims 1 to 11, having a reflective backing layer adjacent the matrix and through which the optical axis passes.
13. An element as claimed in any one of Claims 1 to 11, wherein the shaped polymeric matrix is shaped as a cylinder.
14. An element as claimed in Claim 13, wherein the diluent has an index of refraction less than that of the polymeric matrix and the element is a positive lens.
15. An element as claimed in Claim 13, wherein the diluent has an index of refraction less than that of the polymeric matrix and the element is a negative lens.
16. An element as claimed in Claim 13, wherein the diluent has an index of refraction greater than that of the polymeric matrix and the element is a negative lens.
17. An element as claimed in Claim 13, wherein the diluent has an index of refraction greater than that of the polymeric matrix and the element is a positive lens.
18. An element as claimed in any one of Claims 1 to 11, wherein the shaped polymeric matrix is shaped as a rectangular hexahedron.
19. An element as claimed in Claim 18, wherein the diluent has an index of refraction less than that of the polymeric matrix and the element is a cylindrical lens.
20. An element as claimed in Claim 18, wherein the diluent has an index of refraction greater than that of the polymeric matrix and the element is a cylindrical lens.
21. An element as claimed in Claim 1 or 2 or any one of Claims 12 to 20 as dependent on Claim 1 or 2, wherein the polymer is polystyrene.
22. An element as claimed in Claim 21, wherein the diluent is dimethyl phthalate.
23. An element as claimed in Claim 21, wherein the diluent is di-n-butyl phthalate.
24. An element as claimed in Claim 1 or 2 or any one of Claims 12 to 20 as dependent on Claim 1 or 2, wherein the polymer is poly-(methyl methacrylate).
25. An element as claimed in Claim 24, wherein the diluent is ethylene diacetate.
26. An element as claimed in Claim 1 and substantially as hereinbefore described.
27. A method of making a transparent element for the deflection of incident electromagnetic radiation, which comprises diffusing a transparent diluent into a shaped transparent polymeric matrix of a homogeneous glassy amorphous polymer at a temperature less than the glass transition temperature of the polymer and greater than the glass transition temperature of the polymer-diluent system, the matrix having an optical axis extending between spaced optical surfaces thereof, the diffusion of the diluent into the polymeric matrix forming a continuous gradient in refractive index extending in a direction which is substantially perpendicular to the optical axis of the matrix, and the diluent comprising an organic liquid having a molecular weight of less than 1000, which possesses an index of refraction different from that of the polymer and which is incapable of inducing crystallization of the polymer.
28. A method as claimed in Claim 27, wherein the polymer has a glass transition temperature greater than 27°C.
29. A method as claimed in Claim 28, wherein the polymer has a glass transition temperature greater than 70°C.
30. A method as claimed in any one of Claims 27 to 29, wherein the polymer has a refractive index of from 1.42 to 1.79.
31. A method as claimed in any one of Claims 27 to 30, wherein the polymer has a dispersion index of from 35 to 60.
32. A method as claimed in Claim 31, wherein the polymer has a dispersion index of from 35 to 50.
33. A method as claimed in Claim 31,

wherein the polymer has a dispersion index between 50 and 60.

34. A method as claimed in any one of Claims 27 to 33, wherein the diluent is a solvent for the polymer.

35. A method as claimed in any one of Claims 27 to 34, wherein the diluent has a molecular weight of from 30 to 400.

36. A method as claimed in any one of Claims 27 to 35, wherein the amount of diluent is from 2 to 40 weight %, based on the total weight of polymer and diluent.

37. A method as claimed in any one of Claims 27 to 36, wherein the matrix is shaped as a cylinder and the diluent is diffused into the matrix from a hollow core centred about the optical axis.

38. A method as claimed in any one of Claims 27 to 36, wherein the matrix is shaped as a rectangular hexahedron and the diluent is diffused into the matrix from a cavity centred about the optical axis.

39. A method as claimed in any one of Claims 27 to 36, wherein the matrix is shaped as a cylinder and the diluent is diffused into the matrix from an external source.

40. A method as claimed in any one of Claims 27 to 36, wherein the matrix is shaped

as a rectangular hexahedron and the diluent is diffused into the matrix from an external source.

41. A method as claimed in any one of Claims 27 to 40, wherein the diffusion occurs at a temperature within a range of from 2°C. to 25°C. below the glass transition temperature of the polymer.

42. A method as claimed in Claim 27 or any one of Claims 36 to 41 as dependent on Claim 27, wherein the polymer is polystyrene.

43. A method as claimed in Claim 42, wherein the diluent is dimethyl phthalate.

44. A method as claimed in Claim 42, wherein the diluent is di-n-butyl phthalate.

45. A method as claimed in Claim 27 or any one of Claims 36 to 41 as dependent on Claim 27, wherein the polymer is poly(methylmethacrylate).

46. A method as claimed in Claim 45, wherein the diluent is ethylene diacetate.

47. A method as claimed in Claim 27 and substantially as hereinbefore described.

48. A transparent element made by a method as claimed in Claim 27.

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