WIDE DEPTH OF FOCUS INTRAOCULAR AND CONTACT LENSES

BACKGROUND OF THE INVENTION

It is known in the art of eye care to correct abnormal vision by use of lenses and to alter focus of an image on the retina of the eye. Such lenses can be worn in frames as conventional eye glasses, worn on the surface of the eye as contact lenses, or implanted within the eye as intraocular lenses where a large degree of abnormal vision must be corrected.

Prior art corrective lenses are of fixed power, having a single measure of diopter correction over the entire viewing area of the lens in the case of monofocal lenses, or two or more zones of different fixed diopters in the case of bifocal, multifocal and progressive lenses. Prior art bifocal and multifocal lenses are designed following add power principles. In the case of common eye glasses, two or more differing diopter or power zones many be disposed at vertically displaced regions when the lens is worn to enable the wearer to direct his or her line of sight through the appropriate region depending on the optical distance of the subject to be viewed.

In the case of non-displaced contact lenses and implants, it is not possible t o vary the line of sight with respect to the disposition of the corrective lens. Such lenses have zones with different powers disposed either concentrically or with other geometries at the pupillary plane. This type of construction is illustrated in U.S. Pat. No. 4,637,697 to Freeman for Multifocal Contact Lenses Utilizing Defraction and Refraction. The limited depth of focus of such lenses results in viewing through plural power lenses simultaneously so that the image is, at best, only partially in focus, irrespective of its distance from the viewer.

Other prior art lenses employ phase shift variation between two powers so as to cause destructive and constructive interference at only one very specific given location. In locations other than this on-axis point, there is deviation from the above interference pattern which results in imperfect focusing. These lenses are clear, i.e., have greater than 90% transmission, but a large percent of their power is not focused. Energy which is not focused not only fails to contribute to the focusing of the image, but it actually degrades the image. Such multi-power lenses blur vision and the resulting distractive effect makes their utility questionable. The latter approach is illustrated in U.S. Pat. No. 4,636,211 to Nielsen for a Bifocal Intra-Ocular Lens.

It is also known in the art to color a portion of a contact lens simulating the iris of the eye about a transparent central opening for light to enter the pupil of the eye. This is done for cosmetic purposes and has no appreciable effect on vision. U.S. Pat. No. 4,840,477 to Neefe for Dyed Color Change Contact Lens illustrates this type of construction.

Another use of colored lenses is disclosed in U.S. Pat. No. 3,339,997 to Wesley for Bifocal Ophthalmic Lens having Different Color Distance and Near Vision Zones. There, Wesley teaches the construction of a bifocal ophthalmic lens wherein zones tinted to have different colors are used to focus in the near and distant regions respectively. Wesley depends on the fact that light rays adjacent one end of the visible spectrum focus at a different point than light rays adjacent the other end.

It is also known in the art that depth of focus can be expanded by narrowing the effective pupillary aperture. In the ideal pinhole case, the depth of field is infinite. If two pinholes are used to view an object, an increase in two point discrimination is observed and depth of focus decreases. However, illumination, which is a function of the square of the radius of the pinhole aperture, is severely limited. This solution is also an impractical one in most cases because of diffraction.

An attempt by Wesley to overcome the restricted field of view of pinhole lenses is described in the text entitled Contact Lenses by Philips and Stone, published by Batterworth, in 1989. The text illustrates Wesley's use of opaque portions on lenses to enhance vision according to arbitrary patterns and without reference to any specific mathematical function. Lenses with pluralities of light transmitting apertures surrounded by opaque areas are employed in various symmetric patterns which appear to have been arbitrarily conceived. These patterns which utilize neither gradual shading nor light transmission according to a predetermined mathematical function are believed to be substantially ineffective for failure to control light transmission in accordance with suitable mathematical functions, e.g., a Bessel or Gaussian function.

SUMMARY OF THE INVENTION

The instant invention overcomes the aforementioned problems of prior art lenses, particularly as applied to patients who can not accommodate their vision in order to see objects over a large depth of field such as pseudophakic and presbyopic patients. More specifically the invention includes a lens adapted to be worn on the eye or implanted in the eye for enabling viewing with an extended depth of focus, including a substrate having a surface with a plurality of regions of at least partial transparency, at least one of the regions having a degree of transparency different than that of another of the regions, wherein the first and second regions can be disposed in a predetermined geometry, e.g., concentric, parallel, radial, and the transparency of the regions varies as a mathematical function of their distance from a predetermined origin, e.g., by a Bessel function or Gaussian distribution, the substrate having a tint applied to at least one of the regions to attenuate its transparency. The substrate can be contoured so that at least one of the regions has a non-zero diopter power.

It is therefore an object of the invention to provide a lens adapted to be worn in front of the pupil, such as a contact lens or anterior chamber implant, or in back of the iris, such as a posterior chamber lens implant, for enabling viewing over an extended depth of field.

Another object of the invention is to provide a lens on the eye or implanted in the eye adapted to be worn for enabling viewing over an extended depth of field which permits but does not require contouring of the lens for diopter power.

Still another object of the invention is to provide a lens adapted to be worn on the eye or implanted in the eye for enabling viewing over an extended depth of field by shading selected regions of the lens substrate.

A further object of the invention is to provide a lens adapted to be worn on the eye or implanted in the eye for enabling viewing over an extended depth of field by shading selected regions of the lens substrate to vary transparency as a mathematical function of the location of the regions and to cause phase shifts.