MULTIFOCAL CONTACT LENSES UTILIZING DIFFRACTION AND REFRACTION

RELATED APPLICATIONS

This application is a continuation-in-part of my earlier application Ser. No. 368,362 filed Apr. 14, 1982 entitled Artificial Eye Lens and of my application Ser. No. 533,993 filed Sept. 20, 1983 entitled Improvements in or Relating to Ophthalmic Lenses.

This invention concerns improvements in or relating to contact lenses and relates more particularly to bifocal contact lenses.

The rear surface of a well fitting contact lens has a radius of curvature near that of the cornea. The front surface of the contact lens has a radius of curvature which is determined by the refractive correction required by the wearer. In the case of a bifocal contact lens there is the requirement for additional positive power to replace the failing accommodation of the presbyopic wearer. If this additional power is effected by a change in curvature which, in the case of the rear surface, would generally involve an increase in the radius of curvature, this renders the surface a less good fit on the cornea. It has, however, been proposed in U.S. patent application Ser. No. 368,362 that diffractive power, e.g. provided by a hologram, should be added to the basic refractive power of the contact lens whereby no change in the basic surface curvature is needed.

The present invention also concerns a contact lens which uses the diffraction of light to provide some or all of its optical power. This diffractive power is usually along or nearly along the axis of the contact lens and therefore along the axis of the eye wearing the contact lens. Holograms which provide on-axis power are called in-line or axial holograms. Such holograms have a regular pattern of rings or zones whose centres lie on the axis. Depending largely on the optical effect of each zone, diffractive optical devices with concentric zones have received the names Fresnel Zone Plates (FZPs), Phase Zone Plates, Kinoform Lenses, Thin Film Lenses, Holographic Optical Elements (HOEs); generally the name relates to the method of manufacture. The requirement for diffractive power is the amplitude addition of component light waves having phase differences equivalent to one wavelength to give a new continuous wavefront having a different curvature from the incident wavefront from which the component light waves were generated. The optical term coherence is used to define the conditions under which this can occur. The component light waves are said to be coherent when the phase difference between adjacent zones shows a simple mathematical relationship across the whole aperture of the device.

The Fresnel Zone Plate should not be confused with the Fresnel Lens which has no diffractive power. The Fresnel Lens has facetted zones which have random equivalent phase differences between them. This is due largely to having actual phase differences which are many (e.g. around 100) wavelengths so that the equivalent residual phase difference may be any value between 0 and 2π because of random inaccuracies in the manufacturing method. Any amplitude addition across the lens is insignificant and no useable diffractive power is generated although there is diffractive scattering. The power of a Fresnel Lens is therefore determined solely by refraction at each of the facets of the lens, each of which forms an image of the object. With correct design these images are formed in the same place and the final intensity of the ultimate image is found by adding the intensities of the component images. The diffractive scattering at each facet severely limits the resolution even when all the images are perfectly superimposed.

In the case of optical devices with diffractive power, such as Kinoform Lenses, the diffractive effects are used to form the image and refraction is secondary. The phase difference between each zone is carefully controlled to an accuracy equivalent to about one tenth the wavelength of light. This fundamental requirement for accuracy in the sub-micron region has generally restricted fabrication methods to those using optics and photo-sensitive materials such as holography, scanning Fabry-Perot interferometers and photo-resist material, master drawings with photographic materials and photo-lithographic methods, and thin films which can be etched through photographically generated masks. Such methods have also been used to make diffraction gratings which have proved considerably superior to earlier diffraction gratings made by ruling grooves with a diamond or the like on metal substrates.

According to the present invention there is provided a bifocal contact lens having diffractive power, comprising a plurality of concentric zones arranged so as to cause diffraction of light transmitted through the lens, each zone providing an asymmetric retardation of light across the zone width in a manner which directs light of a design wavelength predominantly into a required order and sign of diffraction at the expense of transmission at zero order and at the expense of transmission at the opposite sign of said required order of diffraction, while light of another wavelength displaced from said design wavelength is predominantly transmitted at zero order in preference to said required order and sign of diffraction, whereby light of said design wavelength from an object at one distance can be focussed by way of said required order and sign of diffraction and light of said other wavelength from an object at another distance can be focussed by way of zero order transmission.

Conveniently said required order of diffraction may be first order diffraction.

Said concentric zones may be defined by surface discontinuities and/or refractive index changes. Said asymmetric retardation across each zone width may be provided by thickness variation or refractive index variation or a combination of both. Preferably the zones are defined, and the asymmetric retardation is provided, by the surface contour of the lens, and preferably the rear surface contour. Thus, in particular, the zones may be defined by steps in the lens surface. The asymmetric retardation may be provided by a stepped surface contour, for example having three, but possibly having more, stepped areas, across each zone, or may alternatively be provided by a smooth curve across the zone, the arrangement in either case being asymmetric across the zone width.

The diffractive power of the lens may be additional to refractive power provided by the material of the lens and the basic curvature of its front and rear surfaces. The above mentioned surface contour can be superimposed on the base curve in a manner which effectively retains the basic curvature. Notably, a curvature of one radius may be made discontinuous by step sizes appropriate for approximation to a curvature of different radius. Where there are stepped areas across each zone,