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(19)

(54) VARIABLE FOCUS LIQUID CRYSTAL LENS

(71) We, THOMSON-BRANDT, a French Body Corporate, of 173, Boulevard Haussmann—75008 Paris—France—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 the reading of information recorded on a track carried by a moving data carrier in the form of a disc or tape. More particularly, the invention relates to a lens arrangement with variable focal length and to an optical reader incorporating this lens arrangement.

The optical reading of information recorded at high density involves the problem of accurately focussing the light beam onto the track to be read, this track having to be illuminated by a spot of very small dimensions to obtain effective restoration of the information. It is known that the movement of an element of the optical reading device can be controlled in dependence upon a focussing error signal.

A movement such as this has the disadvantage of causing acoustic noise which is troublesome in normal use.

The object of the present invention is to provide a projection device of which the focal length is variable under the control of an electrical signal, eliminating the need for any movement in the optical projection device.

According to the invention, there is provided an optical lens arrangement, comprising a hollow glass enclosure two major opposed walls and comprising two transparent electrodes arranged on said walls inside said enclosure, supply means for applying to said two electrodes a variable electrical field, said enclosure being filled with a nematic liquid crystal and being shaped such that the liquid crystal is a lens, the liquid crystal having molecules capable of rotating under the action of said electrical field, the index thus presented by said liquid crystal along the axis of the liquid crystal lens varying between the ordinary index n_o and the extraordinary index n_E of said liquid crystal.

For a better understanding of the invention and to show how the same may be carried into effect, reference will be made to the following description and the attached drawings among which:

Fig. 1 is a diagram explaining the operation of the device according to the invention;

Fig. 2 shows a lens of variable focal length according to the invention;

Fig. 3 shows an optical reader according to the invention.

The invention utilises the effect of the variation in index of a nematic liquid crystal towards a substantially linearly polarized radiation beam, this variation occurring as a direct result of the application of an alternating electrical field parallel to the direction of propagation of the beam which causes the molecules of the liquid crystal to rotate.

An external electrical field may be used for contolling the optical characteristics of a liquid crystal film without destroying the monocrystalline arrangement thereof.

Assuming that a liquid crystal with positive dielectric anisotropy is introduced between two walls, the long axis of the molecules may be oriented in a direction Δ parallel to the walls by unidirectional rubbing the walls or under the influence of a surfactant applied beforehand to the walls (Fig. 1a).

The optical axis of the crystal, which corresponds to the ordinary index n_o, is parallel to the direction Δ of orientation of the molecules. If the incident beam is perpendicular to the walls, as shown in Fig. 1a), and hence to the direction of the molecules, and if it is polarized in the direction Δ, the index of the liquid crystal film is substantially equal to the extraordinary index n_E of the crystal for a liquid crystal having positive dielectric anisotropy. If each of the walls carries a transparent electrode and if an electrical field is applied to the liquid crystal, by means of a voltage source the molecules of the crystal rotate and tend to become oriented parallel to the field $\vec{E}$, as shown in Fig. 1b), and hence to the direction of the beam. The index thus presented to the beam is substantially the

ordinary index n_o, providing the field applied is sufficiently intense.

Finally, if the field is removed, the molecules tend to become reoriented parallel to the walls in the direction of alignment imposed by the walls and the index tends to return to the extraordinary index n_E. However, if the thickness of the liquid crystal film is great, the orienting effect of the walls is weak for the molecules which are remote therefrom when the field is eliminated, and the time required for the index to return to its initial value is long.

It is thus possible for the index of an optical element to be varied by means of an electrical signal. In order to vary the position of the focussing point of a light beam, the optical element used will be in the form of a hollow transparent lens which consists of two walls fixed to one another by means of spaces determining the thickness of the lens and inside which a nematic liquid crystal is introduced. The variation in index under the effect of an electrical signal produces a simultaneous variation in the focal length of the lens thus formed and hence a variation in convergence of a system including the lens.

In practice, to obtain a device of variable focal length which follows the variations of an error signal, it is preferable for the response time to be the same when it is necessary to reduce and then increase the local length.

Preferably the liquid crystal is of a type having a dielectric anisotropy with a sign variable in dependence upon the frequency of an electrical signal applied to it. Certain liquid crystals have a dielectric anisotropy which is positive for a frequency *f* of the field applied below a reference frequency fr, whilst their dielectric anisotropy is negative for a frequency *f* of the field applied above the reference frequency fr at a given temperature T. For example, fr may be equal to 10 kHz at T=25°C.

A liquid crystal lens arrangement according to the invention is shown in section in Fig. 2.

A flat glass wall 1 and a part spherical glass wall 2, separated by an annular spacer 3, are covered internally with transparent electrodes 4 and 5, respectively. These electrodes may be obtained from a mixture of tin oxide and indium oxide applied to the transparent walls by cathode sputtering.

In addition, these electrodes are treated in such a way that the molecules of the liquid nematic crystal introduced through an opening 6 are aligned parallel to the walls in a given direction Δ. This treatment may be carried out by the vacuum deposition onto the electrodes of a convenient material, for example silicon monoxide, with a grazing incidence on the electrodes. The resulting deposits 7 and 8 will tend to align the molecules in the direction Δ imposed when the liquid crystal 9 is introduced into the interior of the lens.

When an a.c. voltage is applied between the two electrodes, the molecules of the liquid crystal are aligned parallel to the walls in the direction Δ or align at right angles to the walls, depending on the frequency of the a.c. voltage applied.

Since the polarization of the incident beam is parallel to the direction Δ, the index of the liquid crystal for the incident beam when *f* is higher than fr is equal to the principal extraordinary index of the crystal and when *f* is lower than fr this index decreases until it reaches the ordinary index n_o when the major axis of the molecules is perpendicular to the walls. Variations in index, Δn, of 0.2 may be obtained with substances of which the mean index is of the order of 1.6.

Fig. 3 shows an optical reader which uses a liquid crystal lens according to the invention. A laser source 30 emits a linearly polarised beam onto a birefringent prism 31. The beam emerging from the prism is oriented by means of a reflecting mirror 32, the reflected beam being substantially colliriated towards a liquid crystal lens 33 of the type described with reference to Fig. 2. This lens causes the beam to converge onto a lens 34, which may be a microscope lens and which focusses the beam it receives at a point O of the reflecting surface 36, carrying the information, of a data carrier 37 after having passed through a quarter-wave plate 35.

This beam is thus reflected by the surface 36 and passes back through the quarter wave plate 35, the lens 34, the liquid crystal lens 33 and is reflected by the mirror 32. Since the beam has passed through the quarter wave plate 35 twice, its polarization has turned through 90°. The beam then passes through the birefringent prism and, since its polarization vector has changed, it emerges from the prism in a direction different from the direction of the incident beam emanating from the laser source. The beam issuing from the prism passes through a cylindrical lens 38 and is detected by an assembly 39 of four photodetector or cells arranged as shown in the Figure in a plane perpendicular to the beam. Two adder amplifiers 40 and 41 are respectively connected to the outputs of two diagonally arranged cells. The outputs of the adders 40 and 41 are connected on the one hand to the inputs of an adder amplifier 42, which supplies the reading signal (V), and on the other hand to the inputs of a differential amplifier 43 which supplies a signal ε characteristics of the focussing deviation, i.e. the distance between the focussing point of the reading beam and the reflecting surface 36 of the carrier. The output of the differential amplifier 43 is connected to a voltage-frequency converter which supplies a constant amplitude signal ε(f) of frequency f=fr when ε=0 and of frequency f above or below fr, depending on the sign of the focussing deviation. This variable frequency

alternating signal is applied between the two electrodes of the liquid crystal lens 33. Thus, the index of the liquid crystal is capable of varying about a mean value equal for example to 1.6, the deviation Δn being of the order of 0.2 for a frequency deviation Δf of 2 kHz. The position adjustment range of the focussing point may thus reach 15 microns with a reading lens having a focal length of 6 mm, the curved wall of the liquid crystal lens having a radius of curvature of 25 cm. The response time of a system of this kind is of the order of 5 ms.

The invention is not limited to the embodiments which have been described and illustrated. In particular, for the liquid crystal lens, the response times of the system, associated with alignment of the molecules of the liquid crystal, may be reduced by giving the lens the form of a Fresnel lens so that the thickness of the lens and hence the thickness of the liquid crystal are smaller.

It is also possible to use a liquid crystal with negative dielectric anisotropy. In this case, the molecules of the liquid crystal are oriented perpendicularly to the walls in the absence of an electrical field, for example by adding a suitable doping agent to the nematic material. When an alternating electrical field of variable amplitude is applied between the electrodes, the molecules align with their major axis perpendicular to the field applied. The index of the crystal which, at rest, is substantially the ordinary index n_o, tends towards the value n_E in the presence of an electrical field.

In this case for the optical reader, if the liquid crystal used in the lens has an index variable in dependence upon the intensity of the field applied, the electrodes of the lens will receive a carrier wave amplitude-modulated by the error signal (ε) because in this case it is with the value of the amplitude of the alternating field created between the electrodes that the alignment of the molecules and hence the variation in index are associated.

Finally, it is possible to combine in the optical reader shown in Fig. 3 the effects of the variations in amplitude and variations in frequency by applying an amplitude- and frequency-modulated signal between the electrodes of the lens.

WHAT WE CLAIM IS:—

1. An optical lens arrangement comprising a hollow glass enclosure having two major opposed walls and comprising two transparent electrodes arranged on said inner walls inside said enclosure, supply means for applying to said two electrodes a variable electrical field, said enclosure being filled with a nematic liquid crystal and being shaped such that the liquid crystal is a lens, the liquid crystal having molecules capable of rotating under the action of said electric field, the index thus presented by said liquid crystal along the axis of the liquid crystal lens varying between the ordinary index n_o and the extraodinary index n_E of said liquid crystal.

2. An optical lens arrangement as claimed in claim 1, wherein said lens comprises means for aligning the molecules of said liquid crystal in the absence of said electrical field parallel to the walls of said enclosure.

3. An optical lens arrangement as claimed in claim 2, wherein when said liquid crystal has a positive dielectric anisotropy, said means for aligning the molecules of liquid crystal are a layer of convenient material applied to said electrodes which ensures alignment of the molecules parallel to said walls of the enclosure in the absence of an electrical field, the electric field being an alternating electrical field of variable amplitude for controlling the index of said liquid crystal.

4. An optical projection device as claimed in claim 3, wherein said lens has a flat wall and a part spherical wall, said electrodes are formed by a mixture of tin oxide and indium oxide and said convenient material is silicon monoxide applied to said electrodes.

5. An optical lens arrangement as claimed in claim 1, wherein said liquid crystal has a dielectric anisotropy variable in dependence upon the frequency of said applied electrical field, the molecules of said crystal being aligned parallel to said electrodes in the absence of the electrical field; rigidified in this position for a field frequency above a limit frequency and tending to become aligned perpendicularly of said electrodes for a field frequency below said limit frequency.

6. An optical reader intended for reading a moving data carrier by a concentrated optical beam, comprising opto-electrical means which supply an error signal proportional to the deviation between the position of said data carrier and the focussing point of said beam,

comprising a lens arrangement as claimed in claim 1, said error signal being applied to a control device which applies a control signal between the electrodes of said lens, said variation in index producing a displacement of said focussing point of the beam so that said deviation is substantially zero.

7. A lens arrangement substantially as hereinbefore described with reference to Figures 1 and 2 of the accompanying drawings.

8. An optical reader substantially as hereinbefore described with reference to Figure 3 of the accompanying drawings.

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2 SHEETS This drawing is a reproduction of the Original on a reduced scale
Sheet 1

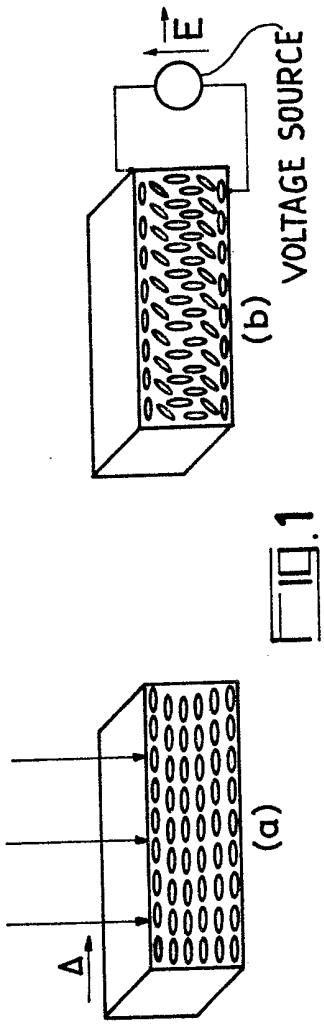


FIG. 1

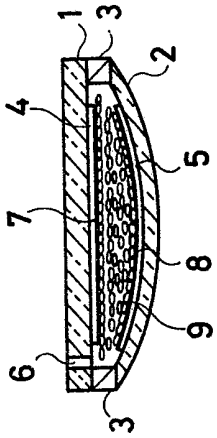
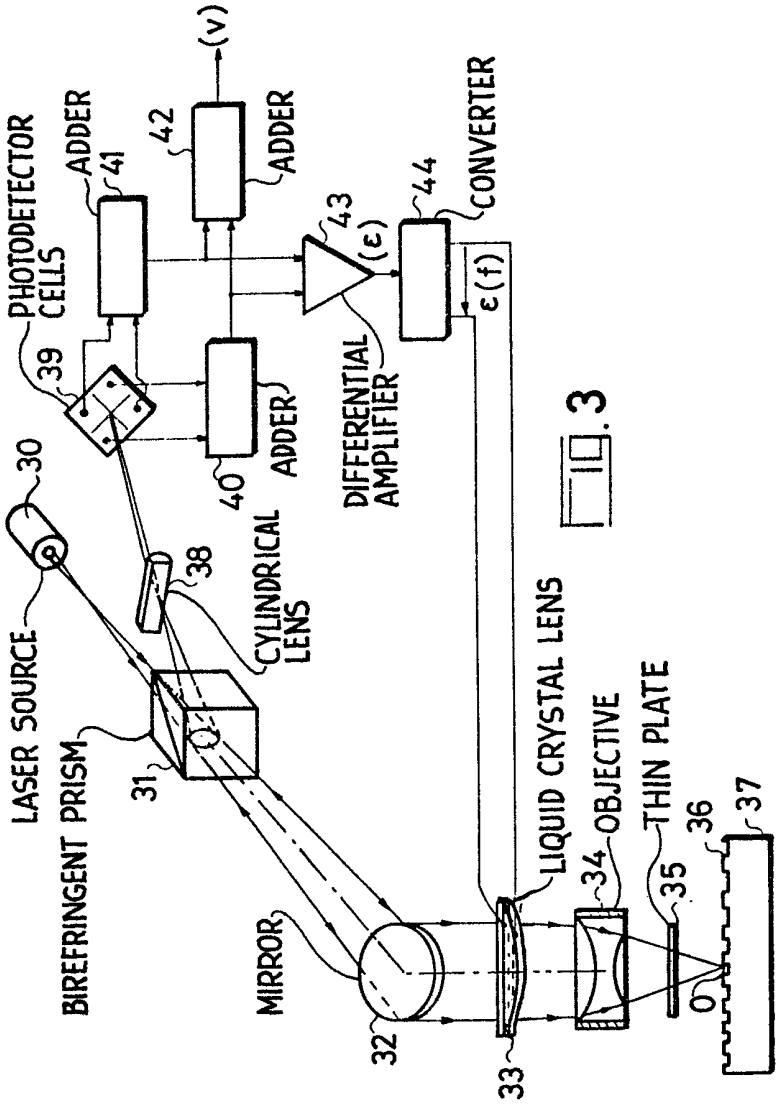


FIG. 2


LASER SOURCE
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BIREFRINGENT PRISM
31
MIRROR
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33
LIQUID CRYSTAL LENS
OBJECTIVE
34
THIN PLATE
35
36
37
CYLINDRICAL LENS
38
PHOTODETECTOR CELLS
39
ADDER
40
ADDER
41
ADDER
42
DIFFERENTIAL AMPLIFIER
43
(ε)
CONVERTER
44
ε(f)
(v)

FIG. 3