VARIABLE-FOCAL-LENGTH LENS

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to a lens whose focal length is variable, and more particularly to a variable focal length lens whose focal length can be varied by utilization of the electro-optic effect without any mechanical movement.

2. Description of the Prior Art

Generally, in variable-focal-length optical lens systems called zoom lenses, variation of the focal length thereof is accomplished by moving predetermined lens groups of the lens system along the optical axis thereof and varying the spacing between those lens groups. In these lens systems, however, a moving mechanism for moving the lens groups is necessary and the result is that performances such as rapid change of the focal length, compactness and reduced cost are not sufficiently satisfied, and the advent of lens systems in which those performances have been enhanced has heretofore been desired.

On the other hand, a variable-focal-length lens which is intended to eliminate the above-noted disadvantages by utilization of the electro-optic effect and which is compact and whose focal length can be rapidly changed is proposed e.g. in U.S. Pat. No. 4,466,703. An example of such variable-focal-length lens according to the prior art is shown in FIG. 1 of the accompanying drawings.

In FIG. 1, reference numeral **1** designates KH_2PO_4 crystal having a linear electro-optic effect (Pockels effect), reference numeral **2** denotes a first transparent electrode portion comprising a plurality of concentric annular transparent electrodes $2_1, 2_2, \ldots, 2_n$, reference numeral **3** designates a lead wire, reference numeral **4** denotes a planar second transparent electrode portion, reference numeral **5** designates a polarizing plate, and reference numeral **6** denotes a power source unit. The power source unit **6** imparts a potential to each of the annular transparent electrodes $2_1, 2_2, \ldots, 2_n$ through the lead wire **3** and applies an electric field of inclined intensity distribution to the crystal **1**, thereby causing the crystal **1** to create a refractive index distribution having a lens action. Also, the focal length of said lens action is varied by varying the electric field to be applied.

However, in the variable-focal-length lens according to the prior art as shown in FIG. 1, means for applying an inclined electric field is necessary to obtain a refractive index distribution having a lens action, and this has led to complicated structure of the lens and the difficulty in manufacturing the lens at low cost. Also, the refractive index distribution thus obtained has been approximately created by the concentric annular electrodes and the reduced performance of the lens such as aberrations has been unavoidable.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide a compact and rapidly operable variable-focal-length lens in which aberrations are small.

It is another object of the present invention to provide a compact and rapidly operable variable-focal-length lens which is simple in structure and inexpensive to manufacture.

The above objects of the present invention are achieved by constructing the variable-focal-length lens by a compound lens including at least one lens formed of electro-optic crystals, means for applying an electric field of uniform intensity distribution to the lens formed of electrooptic crystals, and means for varying the intensity of the electric field to be applied to thereby vary the focal length of the compound lens.

The invention will become fully apparent from the following detailed description thereof taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a schematic view showing a variable-focal-length lens according to the prior art which uses an electrooptic crystal.

FIG. **2** is a schematic view showing a first embodiment of the variable-focal-length lens according to the present invention.

FIG. **3** is a schematic cross-sectional view of a compound lens in the first embodiment of the present invention.

FIG. **4** is a schematic view showing a second embodiment of the variable focal length lens according to the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring to FIG. **2** which shows a first embodiment of the present invention, reference numerals **11** and **12** designate KH_2PO_4 crystals having a linear electrooptic effect (Pockels effect), reference numeral **13** denotes transparent electrode plates, reference numeral **14** designates a polarized light ray, reference numeral **15** denotes a polarizing plate, and reference numeral **16** designates a variable power source. The KH_2PO_4 crystal, as is well known, has an axis of rotatory inversion (z-axis) and two rotation axes (x-axis and y-axis), the z-axis being coincident with the optical axis. When an extraneous electric field E_z is applied in the direction of the z-axis, the index ellipsoid of the crystal is varied and given by the following equation:

$$\frac{x^2+y^2}{n_o^2} + \frac{z^2}{n_e^2} + 2\gamma_{63} E_z xy = 1 \quad (1)$$

where n_o is the principal index of refraction in x and y directions, n_e is the principal index of refraction in z direction, and γ_{63} is the electrooptic constant. When $z'=z$ and the x-axis and y-axis are rotated about the optical axis by 45° to make the coordinates into x'-axis and y'-axis, the coordinates n_x' in which the index ellipsoid cuts the x'-axis and the coordinates n_y' in which the index ellipsoid cuts the y'-axis are respectively obtained as:

$$n_x' = n_o - \frac{n_o^3}{2}\gamma_{63}Ez \quad (2)$$

$$n_y' = n_o + \frac{n_o^3}{2}\gamma_{63}E_z \quad (3)$$

The light travelling in the direction of $z=z'$-axis through the crystals to which the electric field has been applied in z direction is permitted to be polarized only in the directions of the x'-axis and y'-axis, and the indices of refraction for the lights polarized in x' and y'