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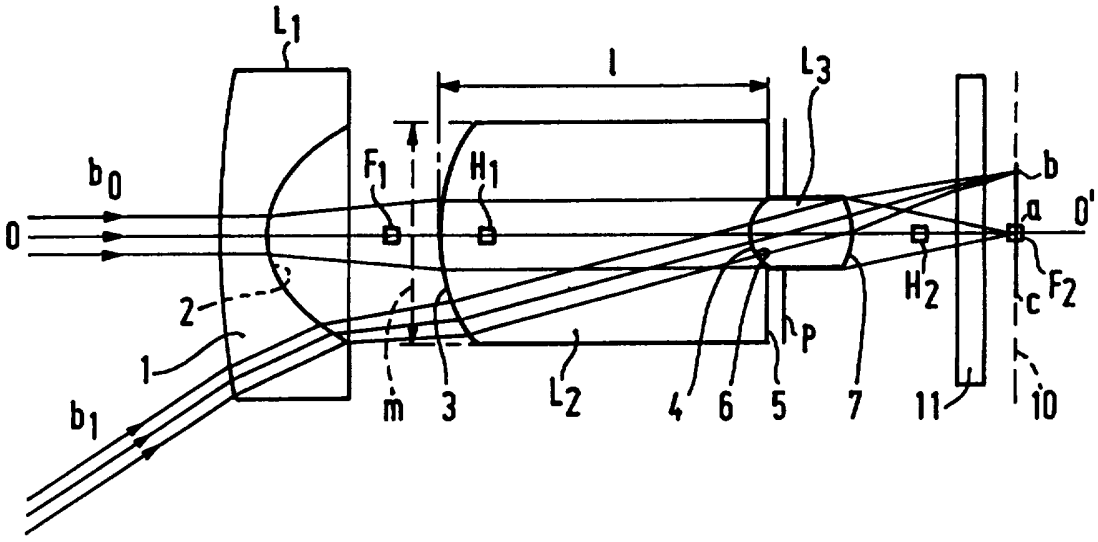
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(54) Title: WIDE ANGLE OBJECTIVE SYSTEM



(57) Abstract

A wide angle objective system is described for, *inter alia*, CCD cameras, which system is compact, inexpensive and satisfactorily corrected. It comprises a front meniscus lens (L_1), a thick convex-concave central lens element (L_2) and a biconvex lens element (L_3), the two last-mentioned elements preferably being cemented together, the pupil (P) being present at the area of the exit surface (4) of the second lens element and the first and the third element (L_1, L_3) being made of, for example, PMMA and the second element (L_2) being made of, for example, PC.

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Wide angle objective system.

The invention relates to an objective system having a large angular aperture for demagnified imaging a scene in an image plane, which system, viewed from the object side, successively comprises:

- a first lens element having a first and a second convex refractive surface,
- a second lens element having a third, convex refractive surface and a fourth refractive surface,
- a third lens element having a fifth refractive surface and a sixth refractive surface.

The invention also relates to an image pick-up device provided with such an objective system.

Such an objective system having, however, an extremely large angular aperture ranging between 125° and 150°, which can be used in a CCD camera, is described in US Patent 5,251,073. This system is of the retrofocus type, which is also referred to as inverse telephoto type, which means that it has a relatively large front focal length at the image side. The known objective system has an F number of F/2.0 and comprises at least four and preferably six glass lens elements. In the known system, the entrance pupil between the first and the second lens element is located in air.

The objective system of the present invention is intended for mass application and for combination with, for example an electronic image sensor, or CCD sensor, having a photosensitive surface diagonal of, for example 4 mm. If the objective system is inexpensive enough, such a combination may be used in a monitoring camera, in a videophone or in a camera which is associated with a personal computer working station coupled to other such stations, so that visual data can be transmitted together with the actual data from one station to other stations. These data can be obtained by scanning a document, also referred to as bitmapping. For said applications, the objective system should have a field of view of the order of 2 x 35° or more, a focal length of, for example 3 mm dependent on the surface of the image sensor for a CCD image sensor having a diagonal of 2 mm and an F

number of, for example F/2.5 so as to pick up scenes of sufficient quality, even at low light levels. Such an objective system cannot be made in accordance with the design described in US Patent 5,251,073 because it would then be too expensive. Moreover, this system has a resolving power which is too small and exhibits too much spherical aberration and astigmatism, the latter effect being particularly troublesome in said bitmapping application.

It is an object of the present invention to provide an objective system for, *inter alia* said application, which system is inexpensive and compact, has a satisfactory colour correction and little astigmatism and distortion, and a satisfactory resolving power. This objective system is characterized in that the sixth refractive surface is concave, in that the pupil of the lens system is present at the area of, or very proximate to the fourth refractive surface, and in that the first and the third lens element are manufactured from the same first material having a first refractive index, and the second lens element is manufactured from a second material having a second refractive index which is different from the first refractive index.

At the area of the fourth surface the angles of incidence of the imaging beam, which angles are determined by the first and second lens elements, are considerably reduced as compared with those of the beam incident on the first lens surface. Since the transition of the second lens element having the second refractive index to the third lens element having the first refractive index is present at the location of the pupil, which transition has a correcting effect for the longitudinal colour error, this error is satisfactorily corrected for all angles of incidence of the imaging beam. Such an effective correction is not realised in the objective system in accordance with US Patent 5,251,073, in which the pupil is not present at the location of, or very proximate to a correction element. The longitudinal colour error is understood to mean that the position of the image plane is dependent on the colour, or wavelength, of the beam or the beam components.

By making use of a thick second lens element having the second refractive index, the transversal colour error of the first lens element having the first refractive index is corrected. The transversal colour error is understood to mean the colour, or wavelength-dependent magnification of the objective system.

The first and third lens elements may be separated from each other by a narrow air gap. An embodiment of the objective system, which is preferred from a manufacturing-technical point of view and as regards stability, is, however, characterized in

that the fourth and the fifth refractive surface have the same curvature and are cemented together.

Use is made of a cementing material whose refractive index is in the range between a value which is slightly larger than the smallest of said first and second refractive indices and a value which is slightly larger than the largest of said refractive indices.

This embodiment is preferably further characterized in that it satisfies the conditions

$$0.20 \leq \frac{K_+}{K_{tot}} \leq 0.60$$

in which K_+ is the positive focal power of the assembly of the second and the third lens element and K_{tot} is the total focal power of the lens system.

An inexpensive embodiment of the objective system having a satisfactory quality is characterized in that the lens elements are entirely manufactured of a synthetic material.

Since all lens elements consist of a transparent synthetic material, the objective system is inexpensive, while it still has the imaging quality desired for said applications. Moreover, lens elements made of such synthetic materials can easily be provided with aspherical surfaces by making use of aspherically profiled moulds for manufacturing the lens elements.

It is to be noted that an objective system for use in a CCD camera and consisting of synthetic material elements is known *per se* from the abstract of Japanese Patent Application 4-107407. However, this system comprises only two lens elements, a negative meniscus lens and a biconvex lens, in which the meniscus lens does not have an aspherical surface. The abstract neither states that the materials of the lens elements are different. The quality of this objective system cannot match that of the objective system according to the present invention, not only in the field but also on the axis.

A preferred embodiment of the objective system using synthetic material elements is characterized in that the first and the third lens element are manufactured of polymethyl methacrylate and the second lens element is manufactured of polycarbonate. Practice has proved that these materials having a refractive index of 1.49 and 1.58,

respectively, are materials having a good optical quality.

In this embodiment the fourth and the fifth lens surface are convex, as viewed from the object side.

The objective system is preferably further characterized in that the fourth lens surface is aspherical.

An aspherical lens surface is understood to mean a surface whose fundamental shape is spherical but whose real shape deviates to a slight extent so as to correct for the spherical aberrations of the fundamental shape of the lens. Since the aspherical surface is present at the location of, or proximate to the pupil of the lens system, it can satisfactorily correct for all angles of incidence of the imaging beam. Since the fourth surface also ensures the correction of the longitudinal colour error, this surface thus has a double correction function in the relevant lens system.

If the objective system is further characterized in that at least one of the first and the second lens surface is aspherical, this system is satisfactorily free from distortion.

By giving also the sixth refractive surface an aspherical shape, an objective system is obtained which has a large F number of the order of F/2.5 with sufficiently small spherical aberrations.

The invention also relates to an image pick-up device provided with an objective system and an opto-electronic image sensor for converting images formed by the objective system into an electronic image signal. This image pick-up device is characterized in that the objective system is a system as described hereinbefore.

If this image pick-up device is further characterized in that the image sensor is a CCD sensor, this device can be implemented in a compact and inexpensive way.

Said synthetic materials, abbreviated to PMMA and PC, have a greater temperature sensitivity than glass. To minimize the effect of this temperature sensitivity and those of the holder accommodating the lens elements on the supplied image signal, the image pick-up device may be further characterized in that the sensor is provided with a fitting for accomodating a lens holder in which the lens elements of the objective system are secured and in that the thermal coefficient of expansion of said fitting is larger than that of the lens holder.

These and other aspects of the invention will be apparent from and

elucidated with reference to the embodiments described hereinafter.

In the drawings

Fig. 1 shows an embodiment of the objective system according to the invention,

Figs. 2a and 2b show the modulation transfer curve and an aberration curve of this system,

Fig. 3 shows this system accommodated in a holder, and

Fig. 4 shows an image pick-up device provided with such an objective system.

The objective system shown in a cross-section in Fig. 1 comprises a first lens element L_1, a second lens element L_2 and a third lens element L_3. The scene to be imaged is at the left-hand side in Fig. 1 and the image plane 10 is at the right-hand side. The first lens element has the shape of a meniscus lens having a slightly curved exit surface 2. This element ensures that a beam portion b_0 entering along the optical axis 00' becomes divergent and that a peripheral beam portion b_1 entering at a relatively large angle α is deflected in such a way that it will extend more parallel to the optical axis and becomes divergent. The lens element L_2 has an entrance surface 3 with such a radius of curvature that it has a collimating effect so that all beam portions can be combined on the exit surface 4 which has a smaller diameter and a smaller radius of curvature than the entrance surface 3. The surface portions 5 at both sides of the exit surface 4 of the lens element L_2 may be plane. The exit surface 4 itself has a diverging effect which is overcompensated by the third lens element so that the beam portions b_0 and b_1 are focused at the points a and b of the image plane 10. All beam portions incident under the optical axis 00' at angles between 0° and α° are focused at points located between the points a and b. The peripheral beam portion incident above the optical axis at an angle $-\alpha$ is focused at a point c in the image plane which is symmetrical with respect to the point b. The beam portions which are incident above the optical axis at angles between 0° and $-\alpha$° are focused at points between said point c and point a. The third lens element has an entrance surface 6 and an opposite curved exit surface 7. The surface 4 of element L_2 is preferably cemented against surface 6 of element L_3. However, these surfaces may also be separated by a narrow air gap.

In Fig. 1, the references H_1 and H_2 denote the main planes of the objective system, F_2 denotes the image focal point and p denotes the exit pupil. For the sake

of completeness, a glass plate 11 is also shown which may be located in front of a sensor and which should be taken into account in designing the objective system.

The refractive indices of the lens element materials, the curvatures of these elements and the distances between these surfaces are preferably chosen to be such that it holds for the focal powers that:

$$0.20 \leq \frac{K_+}{K_{tot}} \leq 0.60$$

in which K_+ is the positive power of the assembly of element L_2 and element L_3, and K_{tot} is the total power of the objective system.

To be able to keep the price of the objective system as low as possible, the lens elements are preferably manufactured of a synthetic material. The first and the third lens element L_1 and L_3 are manufactured of the same transparent synthetic material, preferably polymethyl methacrylate (PMMA) having a refractive index $n_1 = 1.49$, while the second lens element is manufactured of a different synthetic material having a different refractive index, for example polycarbonate (PC) having a refractive index $n_2 = 1.58$. With this choice of synthetic materials, the surfaces 4 and 6 are convex, as is shown in Fig. 1. With a different choice of synthetic materials, these surfaces may become concave. Instead of PMMA, another similar polymer may be used and instead of PC, for example styrene or the material CA-39. The second lens element is a thick element, *i.e.* its length l is considerably larger than the diameter m of its first lens surface 3. With this element of, for example PC the transversal colour error of the negative front element L_1 of, for example PMMA can be corrected. Moreover, the longitudinal colour error is corrected at the transition between the refractive surface 4 of the lens element L_2 and the refractive surface 6 of the lens element L_3, hence at an internal refractive surface.

This internal refractive surface is present in or proximate to the pupil of the objective system, hence at a position where the axes of the different beam portions extend at small angles to the optical axis 00' of the system, so that this correction for these beam portions is equally satisfactory.

The surface 4 is preferably aspherical so that at the location of the pupil it is also possible to correct for the aspherical aberration, which correction is again substantially identical for all beam portions. The surface 4 then has a dual correcting effect.

An aspherical surface may be characterized by

$$Z = \sum A_{2i} \cdot Y^{2i}$$

in which Y is the distance between a point on the aspherical surface and the optical axis of the lens element, Z is the distance between the projection on the optical axis of this point and the point of intersection of the optical axis with the aspherical surface and A_{2i} are the aspherical coefficients.

By giving the surface 2 or surface 1 an aspherical shape, the distortion of the objective system can be maintained sufficiently small. By giving also the surface 7 an aspherical shape, the spherical aberration of the system can even be better corrected so that the system is sufficiently free from spherical aberration, also for the relatively large F number: $F_{2.5}$.

For an embodiment of the objective system in accordance with Fig. 1, having three aspherical surfaces in which the lens elements L_1 and L_3 are made of PMMA and the lens element L_2 is made of PC, the following values, computed from the object side, apply for the axial surface curvatures C_1, the axial distances d between these surfaces and the refractive indices n:

		c (mm^{-1})	d(mm)	n
	1	0.03078		
L_1			1.5	1.49
	2	0.33483		
			5.346	1
	3	0.17400		
L_2			10.055	1.58
	4/6	0.49336		
L_3			3.2118	1.49

7 -0.46157

while the aspherical coefficients A_{2i} of the surfaces 2, 4 and 7 are equal to:

1. $A_2 = 0.167446.10^0$
$A_4 = 0.410699.10^{-2}$
$A_6 = -0.361459.10^{-3}$
$A_8 = 0.332931.10^{-4}$
$A_{10} = -0.942326.10^{-6}$

4. $A_2 = 0.246681.10^0$
$A_4 = 0.163018.10^0$
$A_6 = -0283456.10^{-1}$
$A_8 = 0.332336.10^{-1}$

7. $A_2 = -0.230787.10^0$
$A_4 = -0.904503.10^{-2}$
$A_6 = 0.433596.10^{-2}$
$A_8 = -0.444410.10^{-2}$
$A_{10} = -0.841075.10^{-3}$

If a glass plate 11 having a thickness of 0.19 mm and a refractive index of 1.51 is arranged between the lens surface 7 and the image plane 10, the image field is located at a distance of 5.3132 mm from this lens surface.

This objective system has a focal length of 3 mm, an image diagonal of 4.02 mm, an F number $F_{2.5}$, a field of view of 2 x 38° and a resolving power of more than 50% for a structure of 40 lines/mm. The system is satisfactorily corrected for colour in a wavelength band between 500 and 900 nm.

Fig. 2 shows diagrammatically an embodiment of an image pick-up device according to the invention which comprises the above-described objective system and an image sensor 30, preferably in the form of a CCD sensor as its basic elements.

The objective system has a total power of $K_{tot} = 0.333$ mm^{-1}, the power of the lens element L_1 K. being 0.16 mm^{-1} and the power of the assembly of the lens elements L_2, L_3: K_+ being 0.13 mm^{-1}.

Fig. 2a shows the modulation transfer function (MTF) of this embodiment

of the objective system as a function of the spatial frequency SP (expressed in lines per mm) while Fig. 2b shows the MTF as a function of the distance AS to the optical axis for a spatial frequency of 12.5 lines per mm. It appears that the astigmatism is only small and that the MTF is 50% for a spatial frequency of 40 lines per mm.

In practice, the separate lens elements are accommodated in a common holder 20, as is shown in Fig. 3.

The synthetic materials preferably used for the lens elements L_1, L_2 and L_3 have a larger thermal coefficient of expansion than glass. Moreover, their refractive index is temperature-dependent. Consequently, the optical behaviour of the objective system might change when the ambient temperature varies so that the scene would be imaged out of focus on the image sensor. To prevent this, a material having such a thermal coefficient of expansion may be chosen for the lens holder 20 that the equivalent coefficient of expansion of the objective system causing the change of optical behaviour of this system as a function of the temperature and being determined by:

- the coefficients of expansion of the materials of the lens elements,
- the refractive indices of these materials and their variations with temperature, and
- the dimensions of the lens elements

is equal to the coefficient of expansion of the holder material which is present between the fixations 21, 22 on the holder of the two outer elements of the objective system.

This provides a compensation for temperature variations in the objective system itself. For the principle and further elaboration of this temperature compensation, reference is made to US Patent 4,855,987 in which a temperature-compensated radiation source unit and an optical scanning unit are described.

Fig. 4 shows diagrammatically an embodiment of an image pick-up device according to the invention, which comprises the above-described objective system and an image sensor 30, preferably in the form of a CCD sensor as its basic elements. This sensor is arranged on a holder 31. To be able to correct for temperature variations, a bush 32 may be secured to the holder 31 as an alternative to the compensation described with reference to Fig. 3. This bush is connected at the points 33 to an inner bush 34 within which the lens system L_1, L_2, L_3 is arranged. The thermal coefficient of expansion α_1 of the bush 32 is larger than that, α_2, of the bush 33. If the length of the bush 32 is l_1 and that of the bush 34 is l_2, an offset ΔZ of the objective system with respect to the sensor 30 will occur at a

temperature variation of ΔT, which offset is given by

$$\Delta z = (l_1\alpha_1 - l_2\alpha_2)\Delta T$$

This offset can correct the offset of the focal point of the objective system occurring as a result of the temperature variation ΔT.

Claims:

1. An objective system having a large angular aperture for demagnified imaging a scene in an image plane, which system, viewed from the object side, successively comprises:

- a first lens element having a first and a second convex refractive surface,
- a second lens element having a third, convex refractive surface and a fourth refractive surface,
- a third lens element having a fifth refractive surface and a sixth refractive surface,

characterized in that the sixth refractive surface is concave, in that the pupil of the lens system is present at the area of, or very proximate to the fourth refractive surface, and in that the first and the third lens element are manufactured from the same first material having a first refractive index, and the second lens element is manufactured from a second material having a second refractive index which is different from the first refractive index.

2. An objective system as claimed in Claim 1, characterized in that the fourth and the fifth refractive surface have the same curvature and are cemented together.

3. An objective system as claimed in Claim 2, characterized in that it satisfies the conditions

$$0.20 \leq \frac{K_+}{K_{tot}} \leq 0.60$$

in which K_+ is the positive focal power of the assembly of the second and the third lens element and K_{tot} is the total focal power of the lens system.

4. An objective system as claimed in Claim 1, 2 or 3, characterized in that the lens elements are entirely manufactured of a synthetic material.

5. An objective system as claimed in Claim 4, characterized in that the first and the third lens element are manufactured of polymethyl methacrylate and the second lens element is manufactured of polycarbonate.

6. An objective system as claimed in Claim 1, 2, 3, 4 or 5, characterized in that the fourth lens surface is aspherical.

7. An objective system as claimed in Claim 6, characterized in that at least one of the first and the second lens surface is aspherical.

8. An objective system as claimed in Claim 7, characterized in that the sixth lens surface is aspherical.

9. An objective system as claimed in any one of Claims 1-8, provided with a holder for accommodating the lens elements, characterized in that the lens holder is manufactured of a material having such a thermal coefficient of expansion that the equivalent coefficient of expansion of the lens system causing a change of optical behaviour of this lens system as a function of the temperature and being determined by:

- the coefficients of expansion of the materials of the lens elements,
- the refractive indices of these materials and their variations with temperature, and
- the dimensions of the lens elements is equal to the coefficient of expansion of the holder material which is present between the fixations on the holder of the two outer lens elements.

10. An image pick-up device provided with an objective system and an opto-electronic image sensor for converting images of a scene formed by the objective system into an electronic image signal, characterized in that the objective system is a system as claimed in any one of Claims 1-9.

11. An image pick-up device as claimed in Claim 10, characterized in that the image sensor is a CCD sensor.

12. An image pick-up device as claimed in Claim 10, where not appendant to Claim 9, characterized in that the sensor is provided with a fitting for accommodating a lens holder in which the lens elements of the objective system are secured and in that the thermal coefficient of expansion of said fitting is larger than that of the lens holder.

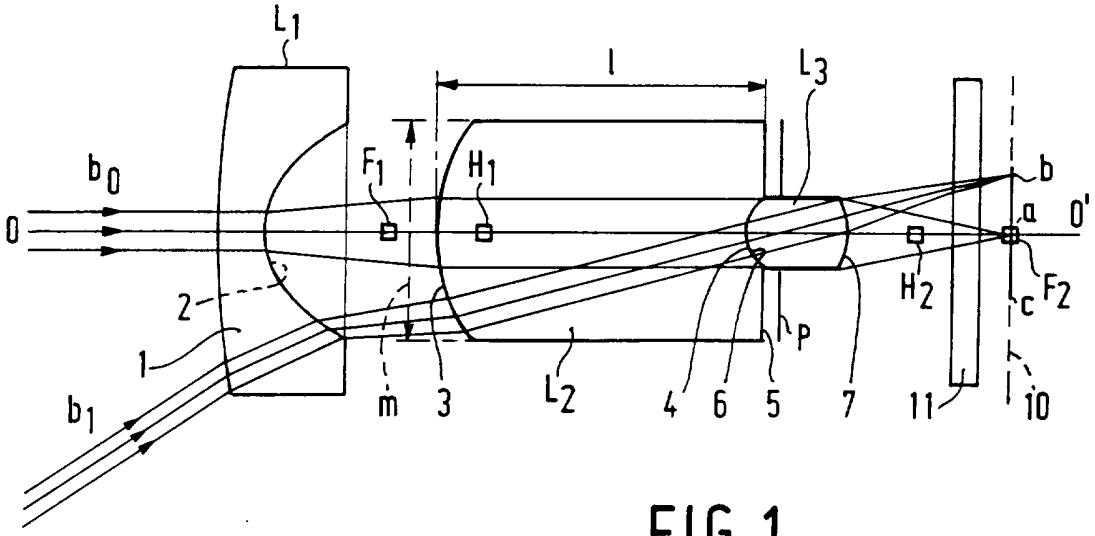


FIG.1

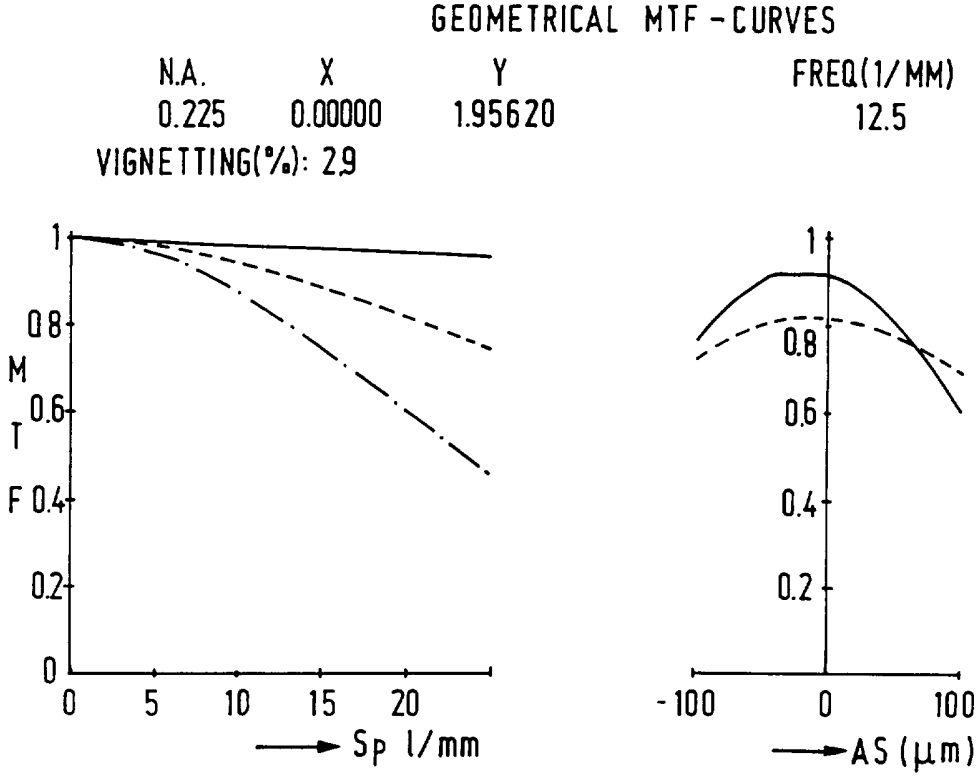


FIG.2a

FIG.2b

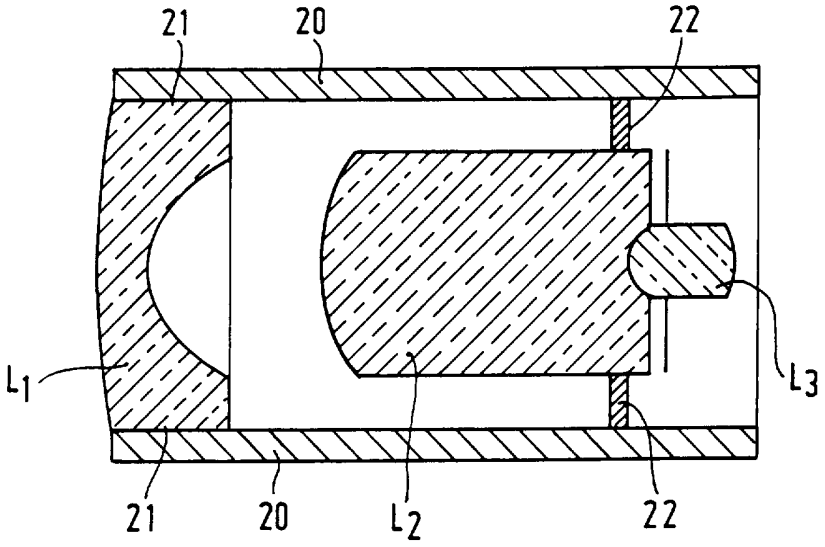


FIG.3

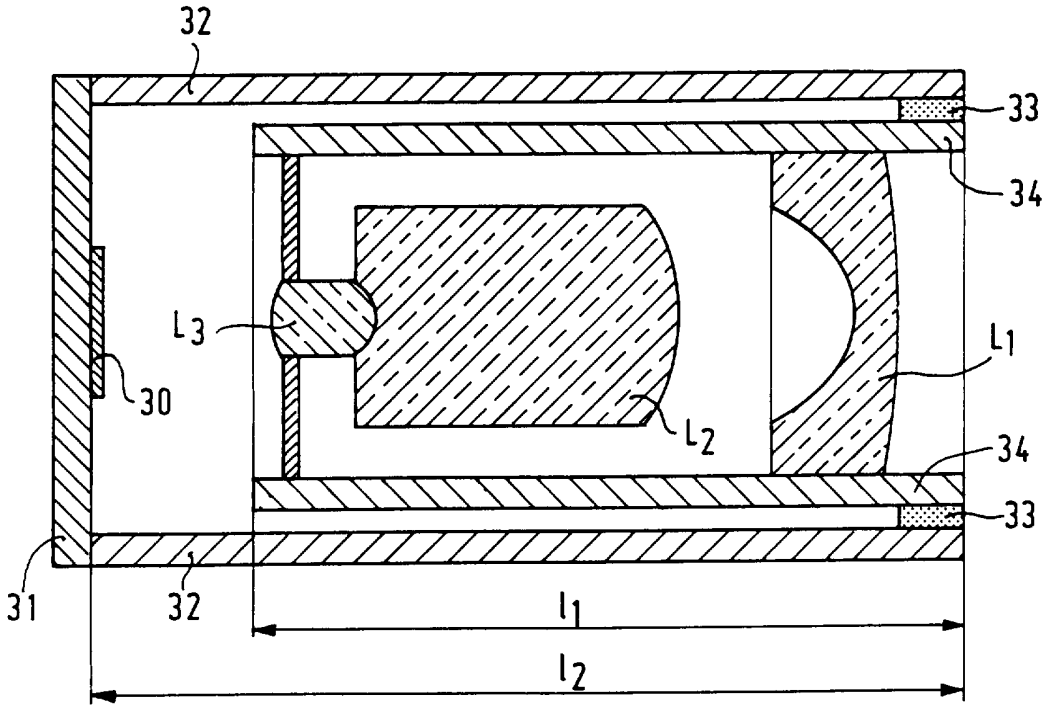


FIG.4

INTERNATIONAL SEARCH REPORT

International application No.
PCT/IB 95/00576

A. CLASSIFICATION OF SUBJECT MATTER

IPC6: G02B 13/04
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC6: G02B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

ORBIT: WPAT, USPM, JAPIO

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5251073 A (UDO SCHAUSS), 5 October 1993 (05.10.93) --	1-12
A	Patent Abstracts of Japan, Vol 16,No 355, P-1394, abstract of JP, A, 4-107407 (NITSUSHIN KOUKI KK), 8 April 1992 (08.04.92) --	1-12
A	DE 4204485 A1 (ASAHI KOGAKU KOGYO K.K.), 10 Sept 1992 (10.09.92) -- --------	1-12

☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
13 December 1995	14.12.95
Name and mailing address of the ISA/ Swedish Patent Office Box 5055, S-102 42 STOCKHOLM Facsimile No. +46 8 666 02 86	Authorized officer Bertil Dahl Telephone No. +46 8 782 25 00

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INTERNATIONAL SEARCH REPORT

30/10/95

International application No.
PCT/IB 95/00576

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