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Imaging lens

Abstract

There is provided an imaging lens with excellent optical characteristics while satisfying demand of wide field of view. An imaging lens comprises, in order from an object side to an image side, a first lens with negative refractive power in a paraxial region, a second lens with positive or negative refractive power having an object-side surface being concave in a paraxial region, a third lens with positive refractive power having a biconvex shape with convex surfaces on the object side and the image side in a paraxial region, and a fourth lens with positive refractive power having an image-side surface being convex in a paraxial region, and predetermined conditional expressions are satisfied.

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Background/Summary

BACKGROUND OF THE INVENTION
Field of the Invention
(1) The present invention relates to an imaging lens which forms an image of an object on a solid-state image sensor such as a CCD sensor or a C-MOS sensor used in an imaging device.
Description of the Related Art
(2) In recent years, it becomes common that camera function forming an image using near-infrared ray is mounted in various products, such as automobiles, biometrics, night-vision monitors, and the

like. Development of products with the camera function will be made accordingly.

(3) The imaging lens mounted in such equipment is required to have a wide field of view and high-resolution performance.

(4) As a conventional imaging lens aiming high performance, for example, the imaging lens disclosed in the following Patent Document 1 has been known.

(5) Patent Document 1 (JP2018-13580A) discloses an imaging lens comprising, in order from an object side, a first lens with positive refractive power, a second lens with negative refractive power, a third lens with positive refractive power, and a fourth lens with positive refractive power, and a relationship between a focal length of the first lens with respect to S-line and a focal length of the overall optical system with respect to S-line satisfies a certain condition.

SUMMARY OF THE INVENTION

(6) However, in lens configurations disclosed in the Patent Document 1, when a wide field of view is to be realized, it is very difficult to correct aberrations at a peripheral area, and excellent optical performance can not be obtained.

(7) The present invention has been made in view of the above-described problems, and an object of the present invention is to provide an imaging lens with high resolution which satisfies demand of the wide field of view and excellently corrects aberrations.

(8) Regarding terms used in the present invention, "a convex surface (a surface being convex)", "a concave surface (a surface being concave)" or "a flat surface (a surface being flat)" of lens surfaces implies a shape of the lens surface in a paraxial region (near the optical axis). "Refractive power" implies the refractive power in a paraxial region. "A pole point" implies an off-axial point on an aspheric surface at which a tangential plane intersects the optical axis perpendicularly. "A total track length" is defined as a distance along the optical axis from an object-side surface of an optical element located closest to the object to an image plane. "The total track length" and "a back focus" is a distance obtained when thickness of an IR cut filter or a cover glass which may be arranged between the imaging lens and the image plane is converted into an air-converted distance.

(9) An imaging lens according to the present invention comprises, in order from an object side to an image side, a first lens with negative refractive power in a paraxial region, a second lens with positive or negative refractive power having an object-side surface being concave in a paraxial region, a third lens with positive refractive power having a biconvex shape with convex surfaces on the object side and the image side in a paraxial region, and a fourth lens with positive refractive power having an image-side surface being convex in a paraxial region.

(10) According to the imaging lens having an above-described configuration, the first lens has the negative refractive power and achieves a wide field of view.

(11) The second lens properly corrects coma aberration, field curvature and distortion. When the second lens has the object-side surface being concave in the paraxial region, the distortion is more properly corrected.

(12) The third lens achieves reduction in a profile, and spherical aberration, astigmatism and the distortion are properly corrected.

(13) The fourth lens properly corrects the coma aberration, the astigmatism, the field curvature and the distortion. When the fourth lens has the image-side surface being convex in the paraxial region, a light ray incident angle to an image sensor can be appropriately controlled. As a result, a lens diameter of the fourth lens can be small and reduction in the diameter of the imaging lens can be achieved.

(14) According to the imaging lens having the above-described configuration, it is preferable that the following conditional expression (1) is satisfied:

$1.60 < |r4|/T2$　　　(1) where r4: a paraxial curvature radius of an image-side surface of the second lens, and T2: a distance along the optical axis from an image-side surface of the second lens to an object-side surface of the third lens.

(15) The conditional expression (1) defines an appropriate range of a relationship between the

paraxial curvature radius of the image-side surface of the second lens and the distance along the optical axis from the image-side surface of the second lens to the object-side surface of the third lens. By satisfying the conditional expression (1), refractive power of the image-side surface of the second lens can be maintained, a light ray incident angle to an object-side surface of the third lens can be appropriately controlled, and the distortion can be properly corrected.

(16) According to the imaging lens having the above-described configuration, it is preferable that the following conditional expression (2) is satisfied:

$2.10 < r5/f < 5.50$ (2) where r5: a paraxial curvature radius of an object-side surface of the third lens, and f: a focal length of the overall optical system of the imaging lens.

(17) The conditional expression (2) defines an appropriate range of the paraxial curvature radius of the object-side surface of the third lens. By satisfying the conditional expression (2), the spherical aberration, the astigmatism and the distortion can be properly corrected.

(18) According to the imaging lens having the above-described configuration, it is preferable that the following conditional expression (3) is satisfied:

$-1.40 < f1/f4 < -0.01$ (3) where f1: a focal length of the first lens, and f4: a focal length of the fourth lens.

(19) The conditional expression (3) defines an appropriate range of a relationship between the focal length of the first lens and the focal length of the fourth lens. By satisfying the conditional expression (3), refractive powers of the first lens and the fourth lens can be appropriately balanced. As a result, chromatic aberration, the coma aberration, the astigmatism, the field curvature and the distortion can be properly corrected.

(20) According to the imaging lens having the above-described configuration, it is preferable that the following conditional expression (4) is satisfied:

$2.85 < D3/T3 < 12.00$ (4) where D3: a thickness along the optical axis of the third lens, and T3: a distance along the optical axis from an image-side surface of the third lens to an object-side surface of the fourth lens.

(21) The conditional expression (4) defines an appropriate range of a relationship between the thickness along the optical axis of the third lens, and the distance along the optical axis from an image-side surface of the third lens to an object-side surface of the fourth lens. By satisfying the conditional expression (4), reduction in the profile can be achieved, a light ray incident angle to an object-side surface of the fourth lens can be appropriately controlled, and the coma aberration, the astigmatism and the distortion can be properly corrected.

(22) According to the imaging lens having the above-described configuration, it is preferable that the following conditional expression (5) is satisfied:

$-3.50 < r3/|r4| < -0.10$ (5) where r3: a paraxial curvature radius of an object-side surface of the second lens, and r4: a paraxial curvature radius of an image-side surface of the second lens.

(23) The conditional expression (5) defines an appropriate range of a relationship between the paraxial curvature radius of the object-side surface of the second lens and the paraxial curvature radius of the image-side surface of the second lens. By satisfying the conditional expression (5), the coma aberration, the field curvature and the distortion can be properly corrected.

(24) According to the imaging lens having the above-described configuration, it is preferable that the following conditional expression (6) is satisfied:

$0.70 < |r7|/f < 5.50$ (6) where r7: a paraxial curvature radius of an object-side surface of the fourth lens, and f: a focal length of the overall optical system of the imaging lens.

(25) The conditional expression (6) defines an appropriate range of the paraxial curvature radius of the object-side surface of the fourth lens. By satisfying the conditional expression (6), the coma aberration, the astigmatism and the distortion can be properly corrected.

(26) According to the imaging lens having the above-described configuration, it is preferable that the following conditional expression (7) is satisfied:

$0.30 < |r7|/(T3+bf) < 2.20$ (7) where r7: a paraxial curvature radius of an object-side surface of

the fourth lens, T3: a distance along the optical axis from an image-side surface of the third lens to an object-side surface of the fourth lens, and bf: a back focus.

(27) The conditional expression (7) defines an appropriate range of a relationship among the paraxial curvature radius of the object-side surface of the fourth lens, the distance along the optical axis from an image-side surface of the third lens to an object-side surface of the fourth lens and the back focus. By satisfying the conditional expression (7), refractive power of the object-side surface of the fourth lens can be maintained, the fourth lens is arranged at an optimum position, and aberration correction function of the lens becomes more effective. As a result, the coma aberration, the astigmatism, the field curvature and the distortion can be properly corrected.

(28) According to the imaging lens having the above-described configuration, it is preferable that the following conditional expression (8) is satisfied:

$$-1.00 < r2/r8 < -0.10 \qquad (8)$$ where r2: a paraxial curvature radius of an image-side surface of the first lens, and r8: a paraxial curvature radius of an image-side surface of the fourth lens.

(29) The conditional expression (8) defines an appropriate range of a relationship between the paraxial curvature radius of the image-side surface of the first lens and the paraxial curvature radius of the image-side surface of the fourth lens. By satisfying the conditional expression (8), the coma aberration, the astigmatism, the field curvature and the distortion can be properly corrected.

(30) According to the imaging lens having the above-described configuration, it is preferable that the following conditional expression (9) is satisfied:

$$8.00 < (T3/f) \times 100 < 40.00 \qquad (9)$$ where T3: a distance along the optical axis from an image-side surface of the third lens to an object-side surface of the fourth lens, and f: a focal length of the overall optical system of the imaging lens.

(31) The conditional expression (9) defines an appropriate range of the distance along the optical axis from the image-side surface of the third lens to the object-side surface of the fourth lens. By satisfying the conditional expression (9), reduction in the profile can be achieved, a light ray incident angle to the object-side surface of the fourth lens can be appropriately controlled, and the astigmatism and the distortion can be properly corrected.

(32) According to the imaging lens having the above-described configuration, it is preferable that the following conditional expression (10) is satisfied:

$$0.40 < r2/f < 2.50 \qquad (10)$$ where r2: a paraxial curvature radius of an image-side surface of the first lens, and f: a focal length of the overall optical system of the imaging lens.

(33) The conditional expression (10) defines an appropriate range of the paraxial curvature radius of the image-side surface of the first lens. By satisfying the conditional expression (10), the distortion can be properly corrected.

(34) According to the imaging lens having the above-described configuration, it is preferable that the following conditional expression (11) is satisfied:

$$-6.50 < r3/f < -1.40 \qquad (11)$$ where r3: a paraxial curvature radius of an object-side surface of the second lens, and f: a focal length of the overall optical system of the imaging lens.

(35) The conditional expression (11) defines an appropriate range of the paraxial curvature radius of the object-side surface of the second lens. By satisfying the conditional expression (11), the coma aberration, the field curvature and the distortion can be properly corrected.

(36) According to the imaging lens having the above-described configuration, it is preferable that the following conditional expression (12) is satisfied:

$$-5.20 < r3/|r7| < -0.50 \qquad (12)$$ where r3: a paraxial curvature radius of an object-side surface of the second lens, and r7: a paraxial curvature radius of an object-side surface of the fourth lens.

(37) The conditional expression (12) defines an appropriate range of a relationship between the paraxial curvature radius of the object-side surface of the second lens and the paraxial curvature radius of the object-side surface of the fourth lens. By satisfying the conditional expression (12), the coma aberration, the astigmatism, the field curvature and the distortion can be properly corrected.

(38) According to the imaging lens having the above-described configuration, it is preferable that the following conditional expression (13) is satisfied:

$10.00 < r5/T3 < 28.50$ (13) where r5: a paraxial curvature radius of an object-side surface of the third lens, and T3: a distance along the optical axis from an image-side surface of the third lens to an object-side surface of the fourth lens.

(39) The conditional expression (13) defines an appropriate range of a relationship between the paraxial curvature radius of the object-side surface of the third lens and the distance along the optical axis from the image-side surface of the third lens to the object-side surface of the fourth lens. By satisfying the conditional expression (13), refractive power of the object-side surface of the third lens can be maintained, a light ray incident angle to an object-side surface of the fourth lens can be appropriately controlled, and the spherical aberration, the astigmatism and the distortion can be properly corrected.

(40) According to the imaging lens having the above-described configuration, it is preferable that the following conditional expression (14) is satisfied:

$-3.00 < |r7|/r8 < -0.10$ (14) where r7: a paraxial curvature radius of an object-side surface of the fourth lens, and r8: a paraxial curvature radius of an image-side surface of the fourth.

(41) The conditional expression (14) defines an appropriate range of a relationship between the paraxial curvature radius of the object-side surface of the fourth lens and the paraxial curvature radius of the image-side surface of the fourth lens. By satisfying the conditional expression (14), the coma aberration, the astigmatism, the field curvature and the distortion can be properly corrected.

(42) According to the imaging lens having the above-described configuration, it is preferable that the following conditional expression (15) is satisfied:

$r8/D4 < -1.50$ (15) where r8: a paraxial curvature radius of an image-side surface of the fourth lens, and D4: a thickness along the optical axis of the fourth lens.

(43) The conditional expression (15) defines an appropriate range of a relationship between the paraxial curvature radius of an image-side surface of the fourth lens and the thickness along the optical axis of the fourth lens. By satisfying the conditional expression (15), reduction in the profile can be achieved, and the coma aberration, the astigmatism, the field curvature and the distortion can be properly corrected.

(44) According to the imaging lens having the above-described configuration, it is preferable that the following conditional expression (16) is satisfied:

$-5.00 < f1/f < -0.90$ (16) where f1: a focal length of the first lens, and f: a focal length of the overall optical system of the imaging lens.

(45) The conditional expression (16) defines an appropriate range of the focal length of the first lens. By satisfying the conditional expression (16), the chromatic aberration and the distortion can be properly corrected.

(46) According to the imaging lens having the above-described configuration, it is preferable that the following conditional expression (17) is satisfied:

$-1.20 < f1/|f2| < -0.15$ (17) where f1: a focal length of the first lens, and f2: a focal length of the second lens.

(47) The conditional expression (17) defines an appropriate range of a relationship between the focal length of the first lens and the focal length of the second lens. By satisfying the conditional expression (17), refractive powers of the first lens and the second lens can be appropriately balanced. As a result, the chromatic aberration, the coma aberration, the field curvature and the distortion can be properly corrected.

Effect of Invention

(48) According to the present invention, there can be provided an imaging lens with high resolution which satisfies demand of the wide field of view and properly corrects aberrations.

Description

(1) FIG. **1** is a schematic view showing an imaging lens in Example 1 according to the present invention.
(2) FIG. **2** shows spherical aberration, astigmatism, and distortion of the imaging lens in Example 1 according to the present invention.
(3) FIG. **3** is a schematic view showing an imaging lens in Example 2 according to the present invention.
(4) FIG. **4** shows spherical aberration, astigmatism, and distortion of the imaging lens in Example 2 according to the present invention.
(5) FIG. **5** is a schematic view showing an imaging lens in Example 3 according to the present invention.
(6) FIG. **6** shows spherical aberration, astigmatism, and distortion of the imaging lens in Example 3 according to the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT
(7) Hereinafter, the preferred embodiment of the present invention will be described in detail referring to the accompanying drawings.
(8) FIGS. **1**, **3** and **5** are schematic views of the imaging lenses in Examples 1 to 3 according to the embodiments of the present invention, respectively.
(9) The imaging lens according to the present invention comprises, in order from an object side to an image side, a first lens L**1** with negative refractive power in a paraxial region, a second lens L**2** with positive or negative refractive power having an object-side surface being concave in a paraxial region, a third lens L**3** with positive refractive power having a biconvex shape with convex surfaces on the object side and the image side in a paraxial region, and a fourth lens L**4** with positive refractive power having an image-side surface being convex in a paraxial region.
(10) A filter IR such as an IR cut filter and a cover glass are arranged between the fourth lens L**4** and an image plane IMG (namely, the image plane of an image sensor). The filter IR is omissible.
(11) An aperture stop ST is arranged between the second lens L**2** and the third lens L**3**, and downsizing in a diameter direction is facilitated.
(12) The first lens L**1** has the negative refractive power and the wide field of view is achieved. The first lens L**1** is formed in a meniscus shape having an object-side surface being convex and an image-side surface being concave in a paraxial region (near the optical axis X). Therefore, spherical aberration and distortion can be properly corrected.
(13) The first lens L**1** may be formed in a biconcave shape having the object-side surface and the image-side surface being concave in a paraxial region (near the optical axis X) as in the Example 2 as shown in FIG. **3**. In this case, chromatic aberration can be more properly corrected.
(14) The second lens L**2** has the negative refractive power and is formed in the biconcave shape having the object-side surface and the image-side surface being concave in the paraxial region. Therefore, the coma aberration, the field curvature and the distortion can be properly corrected.
(15) The refractive power of the second lens L**2** may be positive as in the Example 3 as shown in FIG. **5**. This case is favorable for reduction in the profile.
(16) The second lens L**2** may be formed in a meniscus shape having the object-side surface being concave and the image-side surface being convex in the paraxial region (near the optical axis X) as in the Example 3 as shown in FIG. **5**. In this case, the coma aberration and the distortion can be more properly corrected.
(17) The third lens L**3** has the positive refractive power and is formed in the biconvex shape having the object-side surface and the image-side surface being convex in the paraxial region. Therefore, reduction in the profile can be achieved, and the spherical aberration, the astigmatism and the

distortion can be properly corrected.

(18) The fourth lens L**4** has the positive refractive power and is formed in the biconvex shape having the object-side surface and the image-side surface being convex in the paraxial region. Therefore, reduction in the profile can be achieved, and the coma aberration, the astigmatism, the field curvature and the distortion can be properly corrected. Furthermore, when the image-side surface is convex in the paraxial region, a light ray incident angle to an image sensor can be appropriately controlled. As a result, a lens diameter of the fourth lens can be small and reduction in the diameter of the imaging lens can be achieved.

(19) Regarding the imaging lens according to the present embodiments, it is preferable that all lenses of the first lens L**1** to the fourth lens L**4** are single lenses. Configuration only with the single lenses can frequently use the aspheric surfaces. In the present embodiments, all lens surfaces are formed as appropriate aspheric surfaces, and the aberrations are favorably corrected. Furthermore, in comparison with a case in which a cemented lens is used, workload is reduced, and manufacturing in low cost becomes possible.

(20) Furthermore, the imaging lens according to the present embodiments makes manufacturing facilitated by using a plastic material for the lenses, and mass production in a low cost can be realized.

(21) The material applied to the lens is not limited to the plastic material. By using glass material, further high performance may be aimed. It is preferable that all of lens-surfaces are formed as aspheric surfaces, however, spherical surfaces easy to be manufactured may be adopted in accordance with required performance.

(22) The imaging lens according to the present embodiments shows preferable effect by satisfying the following conditional expressions (1) to (17).

$1.60 < |r4|/T2$ (1)

$2.10 < r5/f < 5.50$ (2)

$-1.40 < f1/f4 < -0.01$ (3)

$2.85 < D3/T3 < 12.00$ (4)

$-3.50 < r3/|r4| < -0.10$ (5)

$0.70 < |r7|/f < 5.50$ (6)

$0.30 < |r7|/(T3+bf) < 2.20$ (7)

$-1.00 < r2/r8 < -0.10$ (8)

$8.00 < (T3/f) \times 100 < 40.00$ (9)

$0.40 < r2/f < 2.50$ (10)

$-6.50 < r3/f < -1.40$ (11)

$-5.20 < r3/|r7| < -0.50$ (12)

$10.00 < r5/T3 < 28.50$ (13)

$-3.00 < |r7|/r8 < -0.10$ (14)

$r8/D4 < -1.50$ (15)

$-5.00 < f1/f < -0.90$ (16)

$-1.20 < f1/|f2| < -0.15$ (17) where D3: a thickness along the optical axis X of the third lens L**3**, D4 a thickness along the optical axis X of the fourth lens L**4**, T2: a distance along the optical axis X from an image-side surface of the second lens L**2** to an object-side surface of the third lens L**3**, T3: a distance along the optical axis X from an image-side surface of the third lens L**3** to an object-side surface of the fourth lens L**4**, bf: a back focus, f: a focal length of the overall optical system of the imaging lens, f1: a focal length of the first lens L**1**, f2: a focal length of the second lens L**2**, f4: a focal length of the fourth lens L**4**, r2: a paraxial curvature radius of an image-side surface of the first lens L**1**, r3: a paraxial curvature radius of an object-side surface of the second lens L**2**, r4: a paraxial curvature radius of an image-side surface of the second lens L**2**, r5: a paraxial curvature radius of an object-side surface of the third lens L**3**, r7: a paraxial curvature radius of an object-side surface of the fourth lens L**4**, and r8: a paraxial curvature radius of an image-side surface of the

fourth lens L**4**.

(23) It is not necessary to satisfy the above all conditional expressions, and by satisfying the conditional expression individually, operational advantage corresponding to each conditional expression can be obtained.

(24) The imaging lens according to the present embodiments shows further preferable effect by satisfying the below conditional expressions (1a) to (17a).

$2.00<|r4|/T2<40.00$ (1a)

$2.50<r5/f<4.40$ (2a)

$-1.25<f1/f4<-0.03$ (3a)

$3.70<D3/T3<10.00$ (4a)

$-2.60<r3/|r4|<-0.30$ (5a)

$1.10<|r7|/f<4.00$ (6a)

$0.45<|r7|/(T3+bf)<1.90$ (7a)

$-0.65<r2/r8<-0.20$ (8a)

$13.00<(T3/f)\times100<30.00$ (9a)

$0.65<r2/f<2.00$ (10a)

$-5.80<r3/f<-2.10$ (11a)

$-4.20<r3/|r7|<-0.75$ (12a)

$13.00<r5/T3<24.00$ (13a)

$-2.00<|r7|/r8<-0.20$ (14a)

$-18.00<r8/D4<-2.50$ (15a)

$-3.50<f1/f<-1.40$ (16a)

$-1.00<f1/|f2|<-0.25$ (17a)

(25) The signs in the above conditional expressions have the same meanings as those in the paragraph before the preceding paragraph.

(26) In this embodiment, the aspheric shapes of the aspheric surfaces of the lens are expressed by Equation 1, where Z denotes an axis in the optical axis direction, H denotes a height perpendicular to the optical axis, R denotes a paraxial curvature radius, k denotes a conic constant, and A4, A6, A8, A10, A12, A14 and A16 denote aspheric surface coefficients.

(27)

$$Z = \frac{\frac{H^2}{R}}{1+\sqrt{1-(k+1)\frac{H^2}{R^2}}} + A_4 H^4 + A_6 H^6 + A_8 H^8 + A_{10} H^{10} + A_{12} H^{12} + A_{14} H^{14} + A_{16} H^{16} \quad \text{[Equation1]}$$

(28) Next, examples of the imaging lens according to this embodiment will be explained. In each example, f denotes a focal length of the overall optical system of the imaging lens, Fno denotes an F-number, ω denotes a half field of view, ih denotes a maximum image height, and TTL denotes a total track length. Additionally, i denotes a surface number counted from the object side, r denotes a paraxial curvature radius, d denotes a distance of lenses along the optical axis (surface distance), Nd denotes a refractive index at d-ray (reference wavelength), and vd denotes an abbe number at d-ray. As for aspheric surfaces, an asterisk (*) is added after surface number i.

Example 1

(29) The basic lens data is shown below in Table 1.

(30) TABLE-US-00001 TABLE 1 Example 1 Unit mm f = 0.39 Fno = 2.60 ω(°) = 57.0 h = 0.59 TTL = 2.98 Surface Data i r d Nd vd (Object) Infinity Infinity   1* 50.0000 0.2980 1.544 55.86 (vd1)   2* 0.5147 0.5973   3* −1.4839 0.2970 1.661 20.37 (vd2)   4* 2.9679 0.0615   5 (Stop) Infinity 0.0969   6* 1.3278 0.3637 1.535 55.61 (vd3)   7* −1.4969 0.0800   8* 0.6018 0.3240 1.535 55.61 (vd4)   9* −1.8867 0.2000 10 Infinity 0.2100 1.517 64.20 11 Infinity 0.5195 Image Plane Infinity ConstituentLens Data Lens StartSurface FocalLength (Wavelength 850 nm) Back Focus 1 1 −0.958 bf 0.858 2 3 −1.459 3 6   1.377 4 8   0.894 Aspheric Surface Data Second Third Fourth FirstSurface Surface Surface Surface k   0.000000E+00 −5.447892E−01 0.000000E+00   0.000000E+00 A4   1.553795E−01 −9.362214E−01 −1.942157E+00

2.537426E+00 A6 −1.039458E−01 −1.036175E+00 2.745899E+01 1.157926E+01 A8 4.147333E−02 −4.537294E−02 −9.703166E+01 1.625506E+03 A10 0.000000E+00 1.020947E+00 1.103522E+02 −1.182447E+04 A12 0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00 A14 0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00 A16 0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00 Sixth Seventh Eighth Ninth Surface Surface Surface Surface k 0.000000E+00 −8.999998E+01 −2.135300E−01 −8.998718E+01 A4 −1.211264E+00 −1.174298E+01 −5.485333E+00 1.495193E+00 A6 3.270475E+01 1.254949E+02 5.621239E+01 4.540025E+00 A8 9.319612E+00 −1.028457E+03 −3.291803E+02 7.691940E+01 A10 −9.170044E+02 5.109394E+03 1.054151E+03 −6.369911E+02 A12 0.000000E+00 −6.500177E+03 −1.545480E+03 1.118991E+03 A14 0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00 A16 0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00

(31) The imaging lens in Example 1 satisfies conditional expressions (1) to (17) as shown in Table

(32) FIG. **2** shows spherical aberration (mm), astigmatism (mm), and distortion (%) of the imaging lens in Example 1. The spherical aberration diagram shows the amount of aberration at each wavelength of 800 nm, 850 nm, and 900 nm. The astigmatism diagram shows the amount of aberration at d-ray on a sagittal image surface S (solid line) and on tangential image surface T (broken line), respectively (same as FIGS. **4** and **6**). As shown in FIG. **2**, each aberration is corrected excellently.

Example 2

(33) The basic lens data is shown below in Table 2.

(34) TABLE-US-00002 TABLE 2 Example 2 Unit mm f = 0.39 Fno = 2.60 ω(°) = 57.0 h = 0.59 TTL = 2.74 Surface Data i r d Nd vd (Object) Infinity Infinity 1* −17.0643 0.2980 1.544 55.86 (vd1) 2* 0.5283 0.5973 3* −1.9449 0.2970 1.661 20.37 (vd2) 4* 1.4095 0.0615 5 (Stop) Infinity 0.0969 6* 1.3278 0.3637 1.535 55.61 (vd3) 7* −1.1399 0.0800 8* 0.6018 0.3240 1.535 55.61 (vd4) 9* −1.5428 0.2000 10 Infinity 0.2100 1.517 64.20 11 Infinity 0.5195 12 Infinity 0.4000 1.517 64.20 Image Plane Infinity 0.0428 ConstituentLens Data Lens StartSurface FocalLength (Wavelength 850 nm) Back Focus 1 1 −0.937 bf 0.830 2 3 −1.201 3 6 1.207 4 8 0.856 Aspheric Surface Data Second Third Fourth FirstSurface Surface Surface Surface k 0.000000E+00 −6.558543E−01 0.000000E+00 0.000000E+00 A4 3.359508E−01 −1.356531E+00 −2.828692E+00 2.202126E+00 A6 −3.123319E−01 5.541637E+00 3.255188E+01 1.934277E+02 A8 1.038267E−01 −4.424488E+01 −2.066004E+02 −1.021489E+04 A10 6.088309E−03 1.342744E+02 3.099240E+03 3.047083E+05 A12 0.000000E+00 −1.826714E+02 −2.613704E+04 6.735707E+05 A14 0.000000E+00 9.487135E+01 7.320020E+04 −7.392892E+07 A16 0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00 Sixth Seventh Eighth Ninth Surface Surface Surface Surface k 0.000000E+00 −8.999998E+01 −2.398328E−02 −8.998718E+01 A4 −2.690882E+00 −2.149588E+01 −1.010096E+01 −6.621282E−01 A6 1.380315E+02 4.817369E+02 1.609144E+02 2.955513E+01 A8 −2.319342E+03 −9.363184E+03 −1.668190E+03 −9.920950E+01 A10 3.039122E+04 1.303491E+05 1.197695E+04 1.625805E+02 A12 −2.456228E+05 −1.132902E+06 −5.682645E+04 −4.041392E+02 A14 7.461257E+05 5.496640E+06 1.574265E+05 0.000000E+00 A16 0.000000E+00 −1.107194E+07 −1.929246E+05 0.000000E+00

(35) The imaging lens in Example 2 satisfies conditional expressions (1) to (17) as shown in Table

(36) FIG. **4** shows spherical aberration (mm), astigmatism (mm), and distortion (%) of the imaging lens in Example 2. As shown in FIG. **4**, each aberration is corrected excellently.

Example 3

(37) The basic lens data is shown below in Table 3.

(38) TABLE-US-00003 TABLE 3 Example 3 Unit mm f = 0.39 Fno = 2.60 ω(°) = 57.0 h = 0.59 TTL = 2.81 Surface Data i r d Nd vd (Object) Infinity Infinity 1* 2.5725 0.2100 1.535 55.61

(vd1)   2* 0.3339 0.5430   3* −1.1038 0.2856 1.535 55.61 (vd2)   4* −0.6373 −0.0033 5 (Stop) Infinity 0.2651   6* 1.1344 0.5500 1.535 55.61 (vd3)   7* −0.4905 0.0696   8* −1.0321 0.3000 1.661 20.37 (vd4)   9* −1.0554 0.1035 10 Infinity 0.2100 1.517 64.20 11 Infinity 0.3444 Image Plane Infinity ConstituentLens Data Lens StartSurface FocalLength (Wavelength 850 nm) Back Focus 1 1 −0.742 bf 0.586 2 3 2.324 3 6 0.726 4 8 17.150 Aspheric Surface Data Second Third Fourth FirstSurface Surface Surface Surface k   6.437952E+00 −4.985764E−01 0.000000E+00 −9.648059E+00 A4   7.069531E−01   1.486620E+00 −1.563448E+00 −5.529587E+00 A6   −1.496478E+00 −1.151408E+01 −3.731671E+01   6.167280E+00 A8 1.420718E+00   2.475420E+02   4.826807E+02   1.640132E+03 A10 −5.991988E−01 −1.354996E+03 −2.574177E+03 −2.896339E+04 A12   1.311280E−06   0.000000E+00 −2.150703E−08 −2.150660E−08 A14 −2.137696E−06   0.000000E+00 −6.591453E−09 −6.592002E−09 A16 −1.971577E−09   0.000000E+00 −2.020505E−09 −2.020495E−09 Sixth Seventh Eighth Ninth Surface Surface Surface Surface k   0.000000E+00 −1.130428E−01 0.000000E+00   0.000000E+00 A4   1.643079E−01 −1.149646E+00 −7.414130E+00 −3.299955E+00 A6   1.199271E+00   5.579617E+01   1.005148E+02   2.760265E+01 A8 −6.137518E+01 −3.842439E+02 −6.088168E+02 −9.372794E+01 A10   1.508339E+02 8.630140E+02   1.280674E+03   1.399977E+02 A12   0.000000E+00 −2.150241E−08 −2.150470E−08 −2.149174E−08 A14   0.000000E+00 −6.591845E−09 −6.592141E−09 −6.591326E−09 A16   0.000000E+00 −2.020525E−09 −2.021018E−09 −2.020843E−09

(39) The imaging lens in Example 3 satisfies conditional expressions (1) to (17) as shown in Table 4.

(40) FIG. **6** shows spherical aberration (mm), astigmatism (mm), and distortion (%) of the imaging lens in Example 3. As shown in FIG. **6**, each aberration is corrected excellently.

(41) In table 4, values of conditional expressions (1) to (17) related to the Examples 1 to 3 are shown.

(42) TABLE-US-00004 TABLE 4 Conditonal Expressions Example 1 Example 2 Example 3 (1) $|r4|/T2$ 18.74 9.71 2.43 (2) $r5/f$ 3.36 3.36 2.87 (3) $f1/f4$ −1.07 −1.10 −0.04 (4) $D3/T3$ 4.55 5.05 7.90 (5) $r3/|r4|$ −0.50 −1.38 −1.73 (6) $|r7|/f$ 1.52 1.52 2.62 (7) $|r7|/(T3 + bf)$ 0.64 0.67 1.57 (8) $r2/r8$ −0.27 −0.34 −0.32 (9) $(T3/f) \times 100$ 20.27 17.73 17.64 (10) $r2/f$ 1.30 1.34 0.85 (11) $r3/f$ −3.76 −4.93 −2.80 (12) $r3/|r7|$ −2.47 −3.23 −1.07 (13) $r5/T3$ 16.60 18.97 16.30 (14) $|r7|/r8$ −0.32 −0.39 −0.98 (15) $r8/D4$ −5.82 −4.66 −3.52 (16) $f1/f$ −2.43 −2.37 −1.88 (17) $f1/|f2|$ −0.66 −0.78 −0.32

(43) When the imaging lens according to the present invention is adopted to a product with the camera function, there is realized contribution to a wide field of view of the camera and also high performance thereof.

DESCRIPTION OF REFERENCE NUMERALS

(44) ST: aperture stop L**1**: first lens L**2**: second lens L**3**: third lens L**4**: fourth lens ih: maximum image height IR: filter CG: cover glass IMG: imaging plane

Claims

1. An imaging lens comprising in order from an object side to an image side, a first lens with negative refractive power in a paraxial region, a second lens with positive or negative refractive power having an object-side surface being concave in a paraxial region, a third lens with positive refractive power having a biconvex shape with convex surfaces on the object side and the image side in a paraxial region, and a fourth lens with positive refractive power having an image-side surface being convex in a paraxial region, wherein the following conditional expressions (1), (2′), (3), (9′), (13″), and (15′) are satisfied:

$1.60<|r4|/T2$ (1)

$2.87<r5/f<3.36$ (2′)

$−1.40<f1/f4<−0.01$ (3)

17.64<$(T3/f)$<20.27　　(9′)

16.30<=$r5/T3$<=18.97　　(13″)

$r8/D4$<=−3.25　　(15′) where r4: a paraxial curvature radius of an image-side surface of the second lens, T2: a distance along an optical axis from an image-side surface of the second lens to an object-side surface of the third lens, r5: a paraxial curvature radius of an object-side surface of the third lens, f: a focal length of the overall optical system of the imaging lens, f1: a focal length of the first lens, f4: a focal length of the fourth lens, T3: a distance along the optical axis from an image-side surface of the third lens to an object-side surface of the fourth lens, r8: a paraxial curvature radius of an image-side surface of the fourth lens, and D4: a thickness along the optical axis of the fourth lens.

2. The imaging lens according to claim 1, wherein the following conditional expression (4) is satisfied:

2.85<$D3/T3$<12.00　　(4) where D3: a thickness along the optical axis of the third lens, and T3: a distance along the optical axis from an image-side surface of the third lens to an object-side surface of the fourth lens.

3. The imaging lens according to claim 1, wherein the following conditional expression (5) is satisfied:

−3.50<$r3/|r4|$<−0.10　　(5) where r3: a paraxial curvature radius of an object-side surface of the second lens, and r4: a paraxial curvature radius of an image-side surface of the second lens.

4. The imaging lens according to claim 1, wherein the following conditional expression (6) is satisfied:

0.70<$|r7|/f$<5.50　　(6) where r7: a paraxial curvature radius of an object-side surface of the fourth lens, and f: a focal length of the overall optical system of the imaging lens.

5. The imaging lens according to claim 1, wherein the following conditional expression (7) is satisfied:

0.30<$|r7|/(T3+bf)$<2.20　　(7) where r7: a paraxial curvature radius of an object-side surface of the fourth lens, T3: a distance along the optical axis from an image-side surface of the third lens to an object-side surface of the fourth lens, and bf: a back focus.

6. The imaging lens according to claim 1, wherein the following conditional expression (8) is satisfied:

−1.00<$r2/r8$<−0.10　　(8) where r2: a paraxial curvature radius of an image-side surface of the first lens, and r8: a paraxial curvature radius of an image-side surface of the fourth lens.