CLAIMS

1. A method for optically inspecting a mold (10) for manufacturing ophthalmic lenses for possible mold defects, the method comprising the steps of:

a. taking an image (41) of the mold (10) along a center axis (Z) of the mold (10) that extends through an apex (15) of the mold and normal to a mold surface (16) at the apex (15) by

illuminating the mold (10) with light (26) incident at an azimuthal illumination angle (ϕ1) and a polar illumination angle (Θ) with regard to the center axis (Z), and

collecting and detecting light (28) reflected or scattered, respectively, from the mold (10) using an imaging system (30) arranged along and aligned with the center axis (Z), wherein a focal plane (31) of the imaging system (30) has an axial position (z1) along the center axis (Z) in the range of the mold (10);

b. repeating step a. for one or a plurality of different azimuthal illumination angles (ϕ2, ϕ3, ϕ4, ϕ5) around the center axis (Z) at the same polar illumination angle (Θ) and the same axial position (z1) of the focal plane (31) to generate a plurality of images (41, 42, 43, 44, 45) of the mold;

c. generating a masked dark field image (54) for each image of the plurality of images (41, 42, 43, 44, 45) taken at the different azimuthal illumination angles (ϕ1, ϕ2, ϕ3, ϕ4, ϕ5) at the same axial position (z1) of the focal plane (31) by applying a respective specular reflection mask (40) to each image of the plurality of images (41, 42, 43, 44, 45) of the mold such as to mask out image regions (44*a*, 44*b*) that include direct specular reflections (23, 24) from the mold (10), so as to obtain a plurality of masked dark field images;

d. generating a focal plane image (61) for the axial position (z1) of the focal plane (31) by averaging pixelwise over the masked dark field images (54) generated at the different azimuthal illumination angles (ϕ1, ϕ2, ϕ3, ϕ4, ϕ5) at the same axial position (z1) of the focal plane (31);

e. repeating steps a. to d. for one or a plurality of different axial positions (z2, z3) of the focal plane (31) to generate a plurality of different focal plane images (61, 62, 63);

f. identifying one or more image features (71, 72, 73, 74) in the plurality of different focal plane images (61, 62, 63), each image feature (71, 72, 73, 74) showing a possible mold defect;

g. determining for each identified image feature (71, 72, 73, 74) a respective sharpest focal plane image (61, 62, 63) of the plurality of different focal plane images (61, 62, 63) by determining for which focal plane image (61, 62, 63) of the plurality of different focal plane images (61, 62, 63) a pre-defined sharpness measure of the identified image feature (71, 72, 73, 74) is at a maximum;

h. generating for each identified image feature (71, 72, 73, 74) a respective image section (81, 82, 83, 84) out of the respective sharpest focal plane image (61, 62, 63), wherein the identified image section (81, 82, 83, 84) includes the identified image feature (71, 72, 73, 74);

i. generating a composed dark field image (90) of the mold (10) by composing the respective image sections (81, 82, 83, 84) for each identified image feature (71, 72, 73, 74) such as to enable determination as to whether the possible defects of the mold (10) allow the mold (10) to be used for manufacturing ophthalmic lenses.

2. The method according to claim 1, wherein the step of identifying one or more image features (71, 72, 73, 74) in the plurality of different focal plane images (61, 62, 63) includes

defining a pixel value threshold between background and non-background image data;

generating a binary identification image of the same size as that of the plurality of different focal plane images (61, 62, 63) by setting a respective pixel of the binary identification image to a first value if a pixel value of a corresponding pixel of at least one of the focal plane images (61, 62, 63) is above the pixel value threshold, and by setting a respective pixel of the binary

identification image to a second value if a pixel value of a corresponding pixel of all focal plane images (61, 62, 63) is below the pixel value threshold;

identifying in the binary identification image one or more pixel patterns consisting of a singular pixel or a plurality of connected pixels set to the first value;

determining for each focal plane image (61, 62, 63) and each identified pixel pattern of the binary identification image whether one or more pixels of the focal plane image (61, 62, 63) within a respective image portion corresponding to a respective one of the identified pixel patterns (172) of the binary identification image have a pixel value that is above the pixel value threshold, and identifying the possibly determined one or more pixels in the focal plane image (61, 62, 63) as an image feature (71, 72, 73, 74) showing a possible mold defect.

3. The method according to claim 1, wherein the step of identifying one or more image features (71, 72, 73, 74) further includes defining for each identified image feature (71, 72, 73, 74) a respective region of interest around the identified image feature (71, 72, 73, 74) such that the identified image feature (71, 72, 73, 74), in particular a corresponding pixel pattern (172) identified in the binary identification image, is included in the region of interest at least for each focal plane image (61, 62, 63) showing the identified image feature.

4. The method according to claim 2, wherein the step of identifying one or more image features (71, 72, 73, 74) further includes defining for each identified image feature (71, 72, 73, 74) a respective region of interest around the identified image feature (71, 72, 73, 74) such that the identified image feature (71, 72, 73, 74), in particular a corresponding pixel pattern (172) identified in the binary identification image, is included in the region of interest at least for each focal plane image (61, 62, 63) showing the identified image feature.

5. The method according to claim 3, wherein the pre-defined sharpness measure of each identified image feature (71, 72, 73, 74) is determined within the respective region of interest only.

6. The method according to claim 3, wherein for each identified image feature (71, 72, 73, 74) the respective image section (81, 82, 83, 84) of the respective sharpest focal plane image (61, 62, 63) corresponds to the respective region of interest.

7. The method according to claim 1, wherein the step of generating a focal plane image (61, 62, 63) includes applying a depth-of-field mask after averaging over the masked dark field images (54) such as to mask out non-sharp image regions showing mold portions which are outside a focal range of the imaging system (30) at the respective axial position (z1, z2, z3) of the focal plane (31).

8. The method according to claim 1, wherein step b. includes repeating step a. such as to take at least three images (41, 42, 43, 44, 45) of the mold (10) corresponding to at least three azimuthal illumination angles (ϕ1, ϕ2, ϕ3, ϕ4, ϕ5), which are angularly equidistantly distributed around the center axis (Z).

9. The method according to claim 1, wherein step b. includes repeating step a. such as to take at least ten images (41, 42, 43, 44, 45) of the mold (10) corresponding to at least ten azimuthal illumination angles (ϕ1, ϕ2, ϕ3, ϕ4, ϕ5), which are angularly equidistantly distributed around the center axis (Z).

10. The method according to claim 1, wherein step e. includes repeating steps a. to d. such as to generate at least three focal plane images (61, 62, 63) corresponding to at least three axial positions (z1, z2, z3) of the focal plane (31) of the imaging system (30), which are equidistantly distributed along the center axis (Z).

11. The method according to claim 1, wherein step e. includes repeating steps a. to d. such as to generate at least ten focal plane images (61, 62, 63) corresponding to at least ten axial positions (z1, z2, z3) of the focal plane (31) of the imaging system (30), which are equidistantly distributed along the center axis (Z).

12. The method according to any claim 1, wherein the polar illumination angle (Θ) is in the range of 1° to 89°.

13. The method according to claim 1, wherein the polar illumination angle (Θ) is in the range of 15° to 45°.

14. The method according to claim 1, wherein the polar illumination angle (Θ) is in the range of 15° to 25°.

15. The method according to claim 1, wherein the mold (10) is successively illuminated by a plurality of LEDs each configured and arranged for illuminating the mold (10) at a respective one of the different azimuthal illumination angles (ϕ1, ϕ2, ϕ3, ϕ4, ϕ5).

16. The method according to claim 1, wherein the mold (10) is illuminated and imaged at a concave side of the mold in case the mold is a female mold, and wherein the mold is illuminated and imaged at a convex side (12) of the mold (10) in case the mold (10) is a male mold (10).

17. An apparatus (1) for optically inspecting a mold (10) for manufacturing ophthalmic lenses, in particular contact lenses, for possible mold defects, in particular for carrying out a method according to any one of the preceding claims, the apparatus comprising:

a mold holder (5) configured to hold the mold (10) in a pre-defined position such that a center axis (Z) of the mold (10) that extends through an apex (15) of the mold (10) and normal to a mold surface (16) at the apex (15) is aligned with a mounting axis (M) of the mold holder (5);

an illumination system (20) configured to illuminate the mold (10) with light (26) incident at a polar illumination angle (Θ) and at different azimuthal illumination angles (ϕ1, ϕ2, ϕ3, ϕ4, ϕ5) with regard to the mounting axis (M); and

an imaging system (30) arranged along and aligned with the mounting axis (M) and configured to collect and detect light (28) reflected or scattered, respectively, from the mold (10), wherein the imaging system (30) is further

configured to adjust a focal plane (31) of the imaging system (30) at different axial positions (z1, z2, z3) along the mounting axis (M) in the range of the mold (10) when being held by the mold holder (5).

18. The apparatus according to claim 17, further comprising a dome (100) covering the mold holder (5) and having an axis of symmetry (S) that extends through an apex (103) of the dome (100) and that is aligned with the mounting axis (M).

19. The apparatus according to claim 18, wherein the dome (100) comprises a plurality of illumination openings (101) circumferentially arranged around the axis of symmetry (S) at different azimuthal positions according to the polar illumination angle (Θ) and the different azimuthal illumination angles (ϕ1, ϕ2, ϕ3, ϕ4, ϕ5), with a light source being arranged in each illumination opening of the plurality of illumination openings (101).

20. The apparatus according to claim 17, wherein the dome (100) comprises a central imaging opening (102) at the apex (103) of the dome (100), with the imaging system being arranged in the central imaging opening (102).