CLAIMS

1. An optical apparatus for imaging micro-objects in an enclosure of a microfluidic device, the optical apparatus comprising:

a structured light modulator configured to receive unstructured light beams from a first light source and reflect or transmit structured light beams suitable for illuminating micro-objects located in enclosure of the microfluidic device;

a first tube lens configured to capture and transmit the structured light beams from the structured light modulator, comprising

a first surface having a convex shape and a first radius of curvature;

a second surface having a second radius of curvature;

a third surface having a concave shape and a third radius of curvature;

a fourth surface having a concave shape and a fourth radius of curvature; and

a clear aperture with a diameter of at least 45 mm;

wherein the first radius of curvature is positive, the third radius of curvature is negative, and the fourth radius of curvature is negative, and

wherein a front focal point and a back focal point of the tube lens are not equally spaced from a midpoint of the tube lens;

an objective lens configured to capture and transmit image light beams from a field of view comprising at least a portion of the enclosure of the microfluidic device;

a first dichroic beam splitter configured to receive and reflect or transmit the structured light beams from the first tube lens, and further configured to receive and transmit or reflect the image light beams from the objective lens;

a second tube lens configured to receive and transmit the image light beams from the first dichroic beam splitter; and

an image sensor configured to receive the image light beams from the second tube lens, wherein the image sensor forms an image of the field of view based upon the image light beams received from the second tube lens.

2. The optical apparatus of claim 1, wherein the structured light modulator comprises an active area of at least 15 mm.

3. The optical apparatus of claim 1, wherein the first tube lens has an effective focal length of about 162 mm or shorter.

4. The optical apparatus of claim 1, wherein the first tube lens has an effective focal length of about 155 mm.

5. The optical apparatus of claim 4, wherein the first tube lens has a numerical aperture of about 0.071 to about 0.085.

6. The optical apparatus of claim 1, wherein the second tube lens has an effective focal length of about 180 mm or longer.

7. The optical apparatus of claim 6, wherein the second tube lens has an effective focal length of about 200 mm.

8. The optical apparatus of claim 1, wherein the second tube lens has a numerical aperture of about 0.063 to about 0.077.

9. The optical apparatus of claim 1, wherein the image sensor comprises an active area of at least 18.0 mm.

10. The optical apparatus of claim 1, wherein the apparatus is characterized by an aperture stop at the back of the objective lens, wherein the aperture stop is at least 25 mm.

11. The optical apparatus of claim 1, wherein the objective lens is configured to minimize aberration in the image of the field of view formed by the image sensor.

12. The optical apparatus of claim 11, wherein the second tube lens is configured to correct a residual aberration of the objective lens.

13. The optical apparatus of claim 11, further comprising a correction lens configured to correct a residual aberration of the objective lens.

14. The optical apparatus of claim 1, wherein the structured light modulator is disposed at a conjugate plane of the image sensor.

15. The optical apparatus of claim 1 further comprising a first light source.

16. The optical apparatus of claim 15, wherein the first light source has a power of at least 10 Watts.

17. The optical apparatus of claim 15 further comprising a second light source.

18. The optical apparatus of claim 17, wherein the second light source is configured to provide unstructured bright field illumination, or wherein the second laser source comprises a laser.

19. The optical apparatus of claim 1, further comprising a second dichroic beam splitter.

20. The optical apparatus of claim 17, further comprising a third light source, wherein the third light source comprises a laser, and wherein the laser of the third light source is configured to heat an internal surface of the microfluidic device and/or a liquid medium located within the enclosure of the microfluidic device.

21. The optical apparatus of claim 1 further comprising a nest, wherein the nest is configured to hold the microfluidic device, provide at least one electrically connection to the microfluidic device, or provide fluidic connections to the microfluidic device.

22. The optical apparatus of claim 1 further comprising a control unit for providing instructions to the structured light modulator, wherein the instructions cause the structured light modulator to produce one or more illumination patterns.

23. A method of manipulating one or more micro-objects of a sample, the method comprising:

loading the sample containing the one or more micro-objects into a microfluidic device having an enclosure comprising a substrate, wherein the substrate comprisesa plurality of light-actuated dielectrophoresis (DEP) electrodes disposed on or comprised by a surface of the substrate;

applying a voltage potential across the microfluidic device;

selectively activating a DEP force adjacent to at least one micro-object located within the microfluidic device by using an optical apparatus to project structured light onto a first position on the surface of the substrate of the microfluidic device, wherein the first position comprises one or more of the plurality of light-actuated DEP electrodes and is located adjacent to a second position on the surface of the substrate, the second position located beneath the at least one micro-object, and wherein the optical apparatus comprises:

a first light source;

a structured light modulator configured to receive unstructured light beams from the first light source and transmit structured light beams suitable for selectively activating the one or more DEP electrodes at the first position on the surface of the substrate of the microfluidic device;

a first tube lens configured to capture and transmit the structured light beams from the structured light modulator;

an objective lens configured to capture the structured light beams transmitted from the first tube lens and project the structured light beams onto the first position on the surface of the substrate of the microfluidic device, and wherein the objective lens is further configured to capture and transmit image light beams reflected or emitted from a field of view comprising at least a portion of the enclosure of the microfluidic device, the field of view encompassing the first and second positions on the surface of the substrate;

a first dichroic beam splitter configured to reflect or transmit to the objective lens the structured light beams received from the first tube lens, and further configured to transmit or reflect image light beams received from the objective lens;

a second tube lens configured to receive and transmit the image light beams from the first dichromic beam splitter; and

an image sensor configured to receive the image light beams from the second tube lens, wherein the image sensor records an image of the field of view based upon the image light beams received from the second tube lens; and

shifting the location of the DEP force generated adjacent to at least one micro-object by using the optical apparatus to move the projected structured light from the first position on the surface of the substrate of the microfluidic device to a third position on the surface of the

substrate, wherein the third position also comprises one or more of the plurality of light-actuated DEP electrodes.

24. The tube lens of claim 1, wherein a Back Focal Length (BFL) of the tube lens is minimized.

25. The tube lens of claim 1, wherein the tube lens has an Effective Focal Length (EFL) of about 155 mm (e.g., 155 mm +/- 1 mm) and a Back Focal Length (BFL) of about 135 mm (e.g., 135 mm +/- 1 mm).

26. The tube lens of claim 1, wherein the tube lens has an Effective Focal Length (EFL) of about 162 mm (e.g., 162 mm +/- 1 mm) and a Back Focal Length (BFL) of about 146 mm (e.g., 146 mm +/- 1mm).

27. The tube lens of claim 1, wherein the tube lens has an Effective Focal Length (EFL) of about 180 mm (e.g., 180 mm +/- 1 mm) and a Back Focal Length (BFL) of about 164 mm (e.g., 164 mm +/- 1 mm).

28. The tube lens of claim 1, wherein the tube lens has an Effective Focal Length (EFL) of about 200 mm (e.g., 200 mm +/- 1 mm) and a Back Focal Length (BFL) of about 191 mm (e.g., 191 mm +/- 1 mm).

29. An optical apparatus for imaging micro-objects in an enclosure of a microfluidic device, the optical apparatus comprising:

a structured light modulator configured to receive unstructured light beams from a first light source and reflect or transmit structured light beams suitable for illuminating micro-objects located in the enclosure of the microfluidic device;

a first tube lens configured to capture and transmit the structured light beams from the structured light modulator;

an objective lens configured to capture and transmit image light beams from a field of view comprising at least a portion of the enclosure of the microfluidic device;

a first dichroic beam splitter configured to receive and reflect or transmit the structured light beams from the first tube lens, and further configured to receive and transmit or reflect the image light beams from the objective lens;

a second tube lens configured to receive and transmit the image light beams from the first dichroic beam splitter, wherein the second tube lens comprises:

a first surface having a convex shape and a first radius of curvature;

a second surface having a second radius of curvature;

a third surface having a concave shape and a third radius of curvature;

a fourth surface having a concave shape and a fourth radius of curvature; and

a clear aperture with a diameter of at least 45 mm;

wherein the first radius of curvature is positive, the third radius of curvature is negative, and the fourth radius of curvature is negative, and

wherein a front focal point and a back focal point of the tube lens are not equally spaced from a midpoint of the tube lens; and

an image sensor configured to receive the image light beams from the second tube lens, wherein the image sensor forms an image of the field of view based upon the image light beams received from the second tube lens.