CLAIMS

1. A lens array for imaging a plurality of image elements in an object plane, the lens array including a plurality of lenslets formed in or on one side of a transparent or translucent material with the image elements disposed on the opposite side, the lens array having a gauge thickness corresponding to the distance from the apex of each lenslet to the object plane, wherein each lenslet has a set of lens parameters, with the gauge thickness and/or at least one lens parameter optimised such that each lenslet has ~~a focal point size~~an effective focal width in the object plane which is substantially equal to the size of the image elements in the object plane, or which varies from the size of the image elements by a predetermined amount.

2. A lens array according to claim 1, wherein the set of lens parameters for the lenslets include two or more of the following: lens width, refractive index, sag height, radius of curvature, conic parameter and Abbe number.

3. A lens array according to claim 1 or claim 2 wherein the gauge thickness of the lens array is optimised with respect to the size of the image elements and the set of lens parameters.

4. A lens array according to any one of claims 1 to 3 wherein the lens parameters are optimised with respect to the size of the image elements and the gauge thickness.

5. A lens array according to claim 3 or claim 4, wherein the gauge thickness of the lens array is less than the focal length of all of the lenslets.

6. A lens array according to any one of the preceding claims, wherein the predetermined amount by which the ~~focal point size~~ effective focal width varies is less than an estimated variability in the size of the image elements.

7. A lens array according to claim 6, wherein the estimated variability is the standard deviation, median absolute deviation or interquartile range of the size of the image elements.

8. A lens array according to any one of the preceding claims, wherein the predetermined amount by which the ~~focal point size~~effective focal width varies from the size of the image elements is not more than 20% of the size of the image elements.

9. A lens array according to any one of the preceding claims, wherein the image elements take the form of dots or lines.

10. A lens array according to any one of the preceding claims, wherein the image elements are applied to a surface on the opposite side of the transparent or translucent material by printing.

11. A lens array according to any one of the preceding claims, wherein the image elements are applied to a surface on the opposite side of the transparent or translucent material by laser marking.

12. A lens array according to ány one of the preceding claims, wherein the lens array includes a substrate of transparent or translucent polymeric material having a first or front surface on or in which the lenslets are formed, and a second or rear surface to which the image elements are applied.

13. A lens array according to claim 12 as appended to claim 10, wherein a plurality of printed dots are printed on the second or rear surface of the substrate in the object plane.

14. A lens array according to claim 10, wherein a plurality of printed dots are printed on a substrate, and the substrate is attached to a transparent or translucent material of the lens array.

15. A lens array according to any one of the preceding claims, wherein the lenslets are formed by an embossing process in a transparent or translucent radiation-curable material.

16. A lens array according to claim 15, wherein the radiation-curable material is applied to a substrate formed from a transparent or translucent material, and the

combined thickness of the substrate and radiation-curable material corresponds to the gauge thickness of the lens array.

17. A lens array according to claim 16, wherein the substrate and the lenslets have substantially the same refractive index.

18. A lens array according to any one of the preceding claims, wherein the set of lens parameters is the same for each of the lenslets.

19. A lens array according to any one of the preceding claims, wherein the lenslets in one area or areas of the lens array have different lens parameters from the lenslets in another area or other areas of the lens array.

20. A lens array according to any one of the preceding claims, wherein the effective focal ~~point size~~width, when averaged over two or more directions within the lobe angle of the lenslet, is substantially equal to the size of the image elements, or varies from the size of the image elements by a predetermined amount.

21. A lens array according to any one of the preceding claims, wherein each lenslet has a cross-section which is a conic section.

22. A lens array according to any one of the preceding claims, wherein each lenslet is rotationally symmetric in the plane of the lens array.

23. A lens array according to any one of the preceding claims, wherein each lenslet is an elongate lenticule having substantially uniform cross section along its length.

24. A lens array according to any one of the preceding claims, wherein the plurality of image elements includes at least two interleaved arrays of image elements.

~~24~~25. A method of manufacturing a lens array for imaging a plurality of image elements in an object plane, the lens array including a plurality of lenslets, the lens array having a gauge thickness corresponding to the distance from the apex of each lenslet to the object plane, the method including the steps of:

determining a scale parameter which is representative of the size of the image elements in at least part of the object plane,

using the scale parameter to optimize the gauge thickness and/or at least one parameter of a set of lens parameters for each lenslet,

and forming the lens array with said gauge thickness and said lens parameters in or on one side of a transparent or translucent material with the image elements being disposed on the opposite side of the transparent or translucent material,

whereby, the lenslets have ~~a focal point size~~an effective focal width in the object plane which is substantially equal to the size of the image elements, or which varies from the size of the image elements by a predetermined amount.

~~25~~26. A method according to claim ~~24~~25, wherein the step of optimizing at least one parameter of the set of lens parameters for the lenslets include two or more of the following: lens width, refractive index, sag height, radius of curvature, conic parameter and Abbe number.

~~26~~27. A method according to claim ~~24~~ 25 ~~to~~ or claim ~~25~~ 26 including the step of optimizing the gauge thickness of the lens array with respect to the size of the image elements and the set of lens parameters.

~~27~~28. A method according to any one of claims ~~24~~ 25 to ~~26~~ 27 including optimizing the lens parameters with respect to the size of the image elements and the gauge thickness.

~~28~~29. A method according to claim ~~26~~ 27 or claim ~~27~~28, including forming the gauge thickness of the lens array to be less than the focal length of all of the lenslets.

~~29~~30. A method according to any one of the preceding claims ~~24~~ 25 to ~~28~~29, including the step of providing that the predetermined amount by which the effective focal ~~point size~~width varies is less than an estimated variability in the size of the image elements.

~~30~~31. A method according to claim ~~29~~30, including the step of providing that the estimated variability is the standard deviation, median absolute deviation or interquartile range of the size of the image elements.

~~31~~32. A method according to any one of the preceding claims ~~24~~–25 to ~~30~~31, including the step of providing that the predetermined amount by which the effective focal ~~point size~~ width varies from the size of the image elements is not more than 20% of the size of the image elements.

~~32~~33. A method according to any one of the preceding claims ~~24~~–25 to ~~31~~32, including forming the image elements as dots or lines.

~~33~~34. A method according to any one of the preceding claims ~~24~~–25 to ~~32~~33, including the step of applying the image elements to a surface on the opposite side of the transparent or translucent material by printing.

~~34~~35. A method according to any one of the preceding claims ~~24~~–25 to ~~33~~34, including the step of applying the image elements to a surface on the opposite side of the transparent or translucent material by laser marking.

~~35~~36. A method according to any one of the preceding claims ~~24~~–25 to ~~34~~35, wherein forming the lens array includes forming the lenslets on or in a first or front surface of a substrate of transparent or translucent polymeric material, and applying the image elements to a second or rear surface.

~~36~~37. A method according to claim ~~35~~–36 as appended to claim ~~33~~34, including the step of printing a plurality of printed dots on the second or rear surface of the substrate in the object plane.

~~37~~38. A method according to claim ~~33~~34, including the step of printing a plurality of dots on a substrate, and attaching the substrate to a transparent or translucent material of the lens array.

~~38~~39. A method according to any one of the preceding claims ~~24~~–25 to ~~37~~38, including the step of forming the lenslets by an embossing process in a transparent or translucent radiation-curable material.

~~39~~40. A method according to claim ~~38~~39, including the step of applying radiation-curable material to a substrate formed from a transparent or translucent material, wherein the combined thickness of the substrate and radiation-curable material corresponds to the gauge thickness of the lens array.

~~40~~41. A method according to claim ~~39~~40, including the step of providing that the substrate and the lenslets have substantially the same refractive index.

~~41~~42. A method according to any one of the preceding claims ~~24~~ 25 to ~~40~~41, including the step of providing that the set of lens parameters is the same for each of the lenslets.

~~42~~43. A method according to any one of the preceding claims ~~24~~ 25 to ~~41~~42, including the step of forming the lenslets in one area or areas of the lens array to have different lens parameters from the lenslets in another area or other areas of the lens array.

~~43~~44. A method according to any one of the preceding claims ~~24~~ 25 to ~~42~~43, including the step of providing that the effective focal ~~point size~~width, when averaged over two or more directions within the lobe angle of the lenslet, is substantially equal to the size of the image elements, or varies from the size of the image elements by a predetermined amount.

~~44~~45. A method according to any one of the preceding claims ~~24~~ 25 to ~~43~~44, including the step of providing that each lenslet has a cross-section which is a conic section.

~~45~~46. A method according to any one of the preceding claims ~~24~~ 25 to ~~44~~45, including the step of providing that each lenslet is rotationally symmetric in the plane of the lens array.

~~46~~47. A method according to any one of the preceding claims ~~24~~ 25 to ~~45~~46, including the step of providing that each lenslet is an elongate lenticule having substantially uniform cross section along its length.

48. A method according to any one of the preceding claims 25 to 47, wherein the plurality of image elements includes at least two interleaved arrays of image elements.

~~47~~49. A method of designing a lens array for imaging a plurality of image elements in an object plane the lens array including a plurality of lenslets and having a gauge thickness corresponding to the distance from the apex of each lenslet to the object plane, the method including the steps of:

estimating a scale parameter which is representative of the size of the image elements in the object plane,

selecting a set of lens parameters for each lenslet, and

designing the lens array using the scale parameter to optimize the gauge thickness and/or at least one lens parameter of the set of lens parameters for each lenslet, wherein each lenslet has ~~a focal point size~~an effective focal width in the object plane which is substantially equal to the size of the image elements, or which varies from the size of the image elements by a predetermined amount.

~~48~~50. A method according to claim ~~47~~49, wherein the set of lens parameters includes refractive index, sag height, lens width, radius of curvature, conic parameter and Abbe number.

~~49~~51. A method according to claim ~~47~~ 49 or claim ~~48~~50, further including the step of measuring the sizes of the image elements in at least part of the object plane, wherein the scale parameter is estimated from the measured sizes of the image elements.

~~50~~52. A method according to claim ~~49~~51, wherein the measurement is performed using a densitometer.

~~51~~53. A method according to claim ~~49~~51, wherein the measurement is performed by directly measuring the sizes of the image elements.

~~52~~54. A method according to any one of claims ~~47~~ 49 to ~~51~~53, wherein the image elements are part of a calibration template.

~~53~~55. A method according to any one of claims ~~47~~ 49 to ~~51~~53, wherein the scale parameter is estimated by computing the mean or maximum of the sizes of the image elements.

~~54~~56. A method according to any one of claims ~~47~~ 49 to ~~52~~54, wherein the scale parameter is estimated using a robust estimator.

~~55~~57. A method according to claim ~~54~~56, wherein the robust estimator is an M-estimator.

~~56~~58. A method according to claim ~~54~~56, wherein the robust estimator is one of the median, upper quartile or interquartile mean of the sizes of the image elements.

59. A method according to any one of the preceding claims 49 to 58, wherein the plurality of image elements includes at least two interleaved arrays of image elements.

~~57~~60. A method of manufacturing an optically variable device, including the steps of:

providing a substrate;

applying image elements to the substrate, said image elements being located in an object plane;

determining a scale parameter which is representative of the size of the image elements;

and forming a plurality of lenslets in a transparent or translucent material on the substrate;

wherein each lenslet has a set of lens parameters determined so that the lenslets have ~~a focal point size~~an effective focal width in the object plane which is substantially equal to the size of the image elements, or which varies from the size of the image elements by a predetermined amount.

~~58~~61. A method according to claim ~~57~~60, wherein the scale parameter is determined by measuring the sizes of the image elements.

~~59~~62. A method according to claim ~~57–~~60 or claim ~~58~~61, including the step of forming the lenslets as part of a lens array having a gauge thickness which is less than the focal length of each of the lenslets.

63. A method according to any one of the preceding claims 60 to 62, wherein the plurality of image elements includes at least two interleaved arrays of image elements.

~~60~~64. An optically variable device, including a substrate and a plurality of lenslets formed in or on the substrate, and a plurality of image elements located in an object plane in or on the substrate, wherein each lenslet has a set of lens parameters determined so that the lenslets have ~~a focal point size~~an effective focal width in the object plane which is substantially equal to the size of the image elements, or which varies from the size of the image elements by a predetermined amount.

~~61~~65. A device according to claim ~~60~~64, wherein the lenslets are part of a lens array having a gauge thickness which is less than the focal length of each of the lenslets.

66. A device according to claim 64 or claim 65, wherein the plurality of image elements includes at least two interleaved arrays of image elements.

~~62~~67. An optically variable device, including a lens array according to any one of claims 1 to 24.

~~63~~68. An optically variable device, including a lens array as manufactured by any one of claims ~~24–~~25 to ~~46~~48.

~~64~~69. A security document including an optically variable device according to any one of claims ~~60–~~64 to ~~63~~68.

~~65~~70. A security document according to claim ~~64~~69, wherein the optically variable device is formed in a window or half-window area of the security document.

CLAIMS

1. A lens array for imaging a plurality of image elements in an object plane, the lens array including a plurality of lenslets formed in or on one side of a transparent or translucent material with the image elements disposed on the opposite side, the lens array having a gauge thickness corresponding to the distance from the apex of each lenslet to the object plane, wherein each lenslet has a set of lens parameters, with the gauge thickness and/or at least one lens parameter optimised such that each lenslet has an effective focal width in the object plane which is substantially equal to the size of the image elements in the object plane, or which varies from the size of the image elements by a predetermined amount.

2. A lens array according to claim 1, wherein the set of lens parameters for the lenslets include two or more of the following: lens width, refractive index, sag height, radius of curvature, conic parameter and Abbe number.

3. A lens array according to claim 1 or claim 2 wherein the gauge thickness of the lens array is optimised with respect to the size of the image elements and the set of lens parameters.

4. A lens array according to any one of claims 1 to 3 wherein the lens parameters are optimised with respect to the size of the image elements and the gauge thickness.

5. A lens array according to claim 3 or claim 4, wherein the gauge thickness of the lens array is less than the focal length of all of the lenslets.

6. A lens array according to any one of the preceding claims, wherein the predetermined amount by which the effective focal width varies is less than an estimated variability in the size of the image elements.

7. A lens array according to claim 6, wherein the estimated variability is the standard deviation, median absolute deviation or interquartile range of the size of the image elements.

8. A lens array according to any one of the preceding claims, wherein the predetermined amount by which the effective focal width varies from the size of the image elements is not more than 20% of the size of the image elements.

9. A lens array according to any one of the preceding claims, wherein the image elements take the form of dots or lines.

10. A lens array according to any one of the preceding claims, wherein the image elements are applied to a surface on the opposite side of the transparent or translucent material by printing.

11. A lens array according to any one of the preceding claims, wherein the image elements are applied to a surface on the opposite side of the transparent or translucent material by laser marking.

12. A lens array according to any one of the preceding claims, wherein the lens array includes a substrate of transparent or translucent polymeric material having a first or front surface on or in which the lenslets are formed, and a second or rear surface to which the image elements are applied.

13. A lens array according to claim 12 as appended to claim 10, wherein a plurality of printed dots are printed on the second or rear surface of the substrate in the object plane.

14. A lens array according to claim 10, wherein a plurality of printed dots are printed on a substrate, and the substrate is attached to a transparent or translucent material of the lens array.

15. A lens array according to any one of the preceding claims, wherein the lenslets are formed by an embossing process in a transparent or translucent radiation-curable material.

16. A lens array according to claim 15, wherein the radiation-curable material is applied to a substrate formed from a transparent or translucent

material, and the combined thickness of the substrate and radiation-curable material corresponds to the gauge thickness of the lens array.

17. A lens array according to claim 16, wherein the substrate and the lenslets have substantially the same refractive index.

18. A lens array according to any one of the preceding claims, wherein the set of lens parameters is the same for each of the lenslets.

19. A lens array according to any one of the preceding claims, wherein the lenslets in one area or areas of the lens array have different lens parameters from the lenslets in another area or other areas of the lens array.

20. A lens array according to any one of the preceding claims, wherein the effective focal width, when averaged over two or more directions within the lobe angle of the lenslet, is substantially equal to the size of the image elements, or varies from the size of the image elements by a predetermined amount.

21. A lens array according to any one of the preceding claims, wherein each lenslet has a cross-section which is a conic section.

22. A lens array according to any one of the preceding claims, wherein each lenslet is rotationally symmetric in the plane of the lens array.

23. A lens array according to any one of the preceding claims, wherein each lenslet is an elongate lenticule having substantially uniform cross section along its length.

24. A lens array according to any one of the preceding claims, wherein the plurality of image elements includes at least two interleaved arrays of image elements.

25. A method of manufacturing a lens array for imaging a plurality of image elements in an object plane, the lens array including a plurality of lenslets, the

lens array having a gauge thickness corresponding to the distance from the apex of each lenslet to the object plane, the method including the steps of:

determining a scale parameter which is representative of the size of the image elements in at least part of the object plane,

using the scale parameter to optimize the gauge thickness and/or at least one parameter of a set of lens parameters for each lenslet,

and forming the lens array with said gauge thickness and said lens parameters in or on one side of a transparent or translucent material with the image elements being disposed on the opposite side of the transparent or translucent material,

whereby, the lenslets have an effective focal width in the object plane which is substantially equal to the size of the image elements, or which varies from the size of the image elements by a predetermined amount.

26. A method according to claim 25, wherein the step of optimizing at least one parameter of the set of lens parameters for the lenslets include two or more of the following: lens width, refractive index, sag height, radius of curvature, conic parameter and Abbe number.

27. A method according to claim 25 or claim 26 including the step of optimizing the gauge thickness of the lens array with respect to the size of the image elements and the set of lens parameters.

28. A method according to any one of claims 25 to 27 including optimizing the lens parameters with respect to the size of the image elements and the gauge thickness.

29. A method according to claim 27 or claim 28, including forming the gauge thickness of the lens array to be less than the focal length of all of the lenslets.

30. A method according to any one of the preceding claims 25 to 29, including the step of providing that the predetermined amount by which the effective focal width varies is less than an estimated variability in the size of the image elements.

31. A method according to claim 30, including the step of providing that the estimated variability is the standard deviation, median absolute deviation or interquartile range of the size of the image elements.

32. A method according to any one of the preceding claims 25 to 31, including the step of providing that the predetermined amount by which the effective focal width varies from the size of the image elements is not more than 20% of the size of the image elements.

33. A method according to any one of the preceding claims 25 to 32, including forming the image elements as dots or lines.

34. A method according to any one of the preceding claims 25 to 33, including the step of applying the image elements to a surface on the opposite side of the transparent or translucent material by printing.

35. A method according to any one of the preceding claims 25 to 34, including the step of applying the image elements to a surface on the opposite side of the transparent or translucent material by laser marking.

36. A method according to any one of the preceding claims 25 to 35, wherein forming the lens array includes forming the lenslets on or in a first or front surface of a substrate of transparent or translucent polymeric material, and applying the image elements to a second or rear surface.

37. A method according to claim 36 as appended to claim 34, including the step of printing a plurality of printed dots on the second or rear surface of the substrate in the object plane.

38. A method according to claim 34, including the step of printing a plurality of dots on a substrate, and attaching the substrate to a transparent or translucent material of the lens array.

39. A method according to any one of the preceding claims 25 to 38, including the step of forming the lenslets by an embossing process in a transparent or translucent radiation-curable material.

40. A method according to claim 39, including the step of applying radiation-curable material to a substrate formed from a transparent or translucent material, wherein the combined thickness of the substrate and radiation-curable material corresponds to the gauge thickness of the lens array.

41. A method according to claim 40, including the step of providing that the substrate and the lenslets have substantially the same refractive index.

42. A method according to any one of the preceding claims 25 to 41, including the step of providing that the set of lens parameters is the same for each of the lenslets.

43. A method according to any one of the preceding claims 25 to 42, including the step of forming the lenslets in one area or areas of the lens array to have different lens parameters from the lenslets in another area or other areas of the lens array.

44. A method according to any one of the preceding claims 25 to 43, including the step of providing that the effective focal width, when averaged over two or more directions within the lobe angle of the lenslet, is substantially equal to the size of the image elements, or varies from the size of the image elements by a predetermined amount.

45. A method according to any one of the preceding claims 25 to 44, including the step of providing that each lenslet has a cross-section which is a conic section.

46. A method according to any one of the preceding claims 25 to 45, including the step of providing that each lenslet is rotationally symmetric in the plane of the lens array.

47. A method according to any one of the preceding claims 25 to 46, including the step of providing that each lenslet is an elongate lenticule having substantially uniform cross section along its length.

48. A method according to any one of the preceding claims 25 to 47, wherein the plurality of image elements includes at least two interleaved arrays of image elements.

49. A method of designing a lens array for imaging a plurality of image elements in an object plane the lens array including a plurality of lenslets and having a gauge thickness corresponding to the distance from the apex of each lenslet to the object plane, the method including the steps of:

estimating a scale parameter which is representative of the size of the image elements in the object plane,

selecting a set of lens parameters for each lenslet, and

designing the lens array using the scale parameter to optimize the gauge thickness and/or at least one lens parameter of the set of lens parameters for each lenslet, wherein each lenslet has an effective focal width in the object plane which is substantially equal to the size of the image elements, or which varies from the size of the image elements by a predetermined amount.

50. A method according to claim 49, wherein the set of lens parameters includes refractive index, sag height, lens width, radius of curvature, conic parameter and Abbe number.

51. A method according to claim 49 or claim 50, further including the step of measuring the sizes of the image elements in at least part of the object

plane, wherein the scale parameter is estimated from the measured sizes of the image elements.

52. A method according to claim 51, wherein the measurement is performed using a densitometer.

53. A method according to claim 51, wherein the measurement is performed by directly measuring the sizes of the image elements.

54. A method according to any one of claims 49 to 53, wherein the image elements are part of a calibration template.

55. A method according to any one of claims 49 to 53, wherein the scale parameter is estimated by computing the mean or maximum of the sizes of the image elements.

56. A method according to any one of claims 49 to 54, wherein the scale parameter is estimated using a robust estimator.

57. A method according to claim 56, wherein the robust estimator is an M-estimator.

58. A method according to claim 56, wherein the robust estimator is one of the median, upper quartile or interquartile mean of the sizes of the image elements.

59. A method according to any one of the preceding claims 49 to 58, wherein the plurality of image elements includes at least two interleaved arrays of image elements.

60. A method of manufacturing an optically variable device, including the steps of:

providing a substrate;

applying image elements to the substrate, said image elements being located in an object plane;

determining a scale parameter which is representative of the size of the image elements;

and forming a plurality of lenslets in a transparent or translucent material on the substrate;

wherein each lenslet has a set of lens parameters determined so that the lenslets have an effective focal width in the object plane which is substantially equal to the size of the image elements, or which varies from the size of the image elements by a predetermined amount.

61. A method according to claim 60, wherein the scale parameter is determined by measuring the sizes of the image elements.

62. A method according to claim 60 or claim 61, including the step of forming the lenslets as part of a lens array having a gauge thickness which is less than the focal length of each of the lenslets.

63. A method according to any one of the preceding claims 60 to 62, wherein the plurality of image elements includes at least two interleaved arrays of image elements.

64. An optically variable device, including a substrate and a plurality of lenslets formed in or on the substrate, and a plurality of image elements located in an object plane in or on the substrate, wherein each lenslet has a set of lens parameters determined so that the lenslets have an effective focal width in the object plane which is substantially equal to the size of the image elements, or which varies from the size of the image elements by a predetermined amount.

65. A device according to claim 64, wherein the lenslets are part of a lens array having a gauge thickness which is less than the focal length of each of the lenslets.

66. A device according to claim 64 or claim 65, wherein the plurality of image elements includes at least two interleaved arrays of image elements.

67. An optically variable device, including a lens array according to any one of claims 1 to 24.

68. An optically variable device, including a lens array as manufactured by any one of claims 25 to 48.

69. A security document including an optically variable device according to any one of claims 64 to 68.

70. A security document according to claim 69, wherein the optically variable device is formed in a window or half-window area of the security document.