~~WHAT IS CLAIMED IS:~~

CLAIMS

1. An adaptive illumination system comprising:

~~-~~an array of independently controllable LEDs;

a pre-collimator arranged to partially collimate light emitted by the LEDs; and

~~-~~a metalens ~~spaced apart~~positioned on an opposite side of the pre-collimator from the ~~array of~~ LEDs~~, the metalens~~ and comprising at least a first array of niobium pentoxide nanoantennas arranged to affect phase and amplitude of the light ~~emitted~~partially collimated by the ~~LEDs so as~~pre-collimator to ~~at least partially~~ further collimate the light,

the metalens being positioned and structurally arranged so that light emitted from different LEDs of the array is directed to corresponding differing predefined far-field regions.

2. The adaptive illumination system of claim 1, wherein each LED is a segment of a monolithic structure.

3. The adaptive illumination system of claim 2, wherein each LED has dimensions in a plane of the array of less than or equal to 500 microns.

4. The adaptive illumination system of claim 3, wherein each LED has dimensions in the plane of the array of less than or equal to 100 microns.

5. The adaptive illumination system of claim 1, wherein the ~~niobium pentoxide nanoantennas have cylindrical shapes and are arranged with their long axes perpendicular to a plane of the metalens.~~

~~6. The adaptive illumination system of claim 1, further comprising a pre-collimator positioned between the LED array and the metalens, the pre-collimator being arranged so as to at least partially collimate the light.~~

~~7. The adaptive illumination system of claim 6, wherein the~~ pre-collimator comprises an array of nanoantennas arranged to affect phase and amplitude of the light emitted by the LEDs ~~so as~~ to partially collimate the light.

~~8~~6. The adaptive illumination system of claim ~~7~~5, wherein the nanoantennas in the pre-collimator are formed from niobium pentoxide, gallium nitride, silicon nitride, titanium dioxide, or hafnium oxide.

~~9~~7. The adaptive illumination system of claim ~~8~~6, wherein the nanoantennas in the pre-collimator are formed from niobium pentoxide.

~~10. The adaptive illumination system of claim 7, the first array of niobium pentoxide nanoantennas and the nanoantennas in the pre-collimator being positioned on opposite first and second surfaces of a substrate, respectively.~~

~~11~~8. The adaptive illumination system of claim 1, wherein the metalens ~~includes~~comprises a substrate, and the first array of niobium pentoxide nanoantennas is arranged on a first surface of the substrate.

~~12~~9. The adaptive illumination system of claim ~~11, the metalens including~~8, comprising a second array of niobium pentoxide nanoantennas arranged to affect phase and amplitude of the light ~~so as~~partially collimated by the pre-collimator to further collimate the light, the second array of niobium pentoxide nanoantennas ~~being~~ arranged on a second surface of the substrate opposite from the first surface of the substrate.

10. ~~13.~~ The adaptive ~~light~~ illumination system of claim ~~12, further comprising a pre-collimator positioned between~~ 1, wherein the ~~LED array~~ niobium pentoxide nanoantennas have cylindrical shapes and are arranged with their long axes perpendicular to a plane of the metalens~~, the pre-collimator being arranged so as to at least partially collimate the light.~~ .

~~14~~11. The adaptive light illumination system of claim ~~13~~1, wherein each LED is a segment of a monolithic structure~~.~~, the metalens comprises a substrate, and the first array of niobium pentoxide nanoantennas is arranged on a first surface of the substrate, comprising a second array of niobium pentoxide nanoantennas arranged to

affect phase and amplitude of the light partially collimated by the pre-collimator to further collimate the light, the second array of niobium pentoxide nanoantennas arranged on a second surface of the substrate opposite from the first surface of the substrate.

~~15. The~~12. An adaptive illumination system ~~of claim 12, wherein~~comprising:

an array of independently controllable LEDs; and

a metalens spaced apart from the array of LEDs and comprising:

a substrate;

a first array of niobium pentoxide nanoantennas arranged on a first surface of the substrate to affect phase and amplitude of light emitted by the LEDs to partially collimated the light; and

a second array of niobium pentoxide nanoantennas arranged on a second surface of the substrate opposite from the first surface to affect phase and amplitude of light emitted by the LEDs to further collimate the ~~light.~~ light,

the metalens being positioned and structurally arranged so that light emitted from different LEDs of the array is directed to corresponding differing predefined far-field regions.

13. An adaptive illumination system comprising:

an array of independently controllable LEDs; and

a metalens spaced apart from the array of LEDs, the metalens comprising:

a substrate;

a first array of niobium pentoxide nanoantennas arranged on a first surface of the substrate to affect phase and amplitude of light emitted by the LEDs to partially collimated the light; and

a second array of niobium pentoxide nanoantennas arranged on a second surface of the substrate opposite from the first surface to affect phase and amplitude of light emitted by the LEDs to further collimate the light,

wherein:

both the first and the second array of niobium pentoxide nanoantennas extend to outer portions of the metalens;

——the first array of niobium pentoxide nanoantennas covers central regions of the metalens around an optical axis of the metalens; and

——the second array of niobium pentoxide nanoantennas does not cover the central region of the metalens.

~~16~~14. The adaptive illumination system of claim ~~15~~13, wherein each LED is a segment of a monolithic structure.

~~17~~15. The adaptive illumination system of claim ~~16~~14, wherein each LED has dimensions in a plane of the array of less than or equal to 500 microns.

~~18~~16. The adaptive illumination system of claim ~~17~~15, wherein each LED has dimensions in the plane of the array of less than or equal to 100 microns.

~~19~~17. The adaptive illumination system of claim 12, wherein the niobium pentoxide nanoantennas have cylindrical shapes and are arranged with their long axes perpendicular to a plane of the metalens.

~~20~~18. A mobile device comprising:

——a camera;

a flash illumination system comprising:

a monolithic array of independently controllable LEDs;

a metalens spaced apart from the ~~adaptive illumination system of any one~~array of ~~claims 1 through 19;~~LEDs and comprising at least a first array of niobium pentoxide nanoantennas arranged to affect phase and amplitude of light emitted by the LEDs to at least partially collimate the light, the metalens being positioned and structurally arranged so that light emitted from different LEDs of the array is directed to corresponding differing predefined far-field regions; and

——a controller configured to operate the LEDs to match a field of view of the flash illumination system to a field of view of the camera.

~~21. A display system comprising:~~

19. The mobile device of claim 18, wherein each LED has dimensions in a plane of the array of less than or equal to 500 microns.

20. The mobile device of claim 18, wherein the metalens comprises a substrate, and the first array of niobium pentoxide nanoantennas is arranged on a first surface of the substrate.

21. The mobile device of claim 20, comprising a second array of niobium pentoxide nanoantennas arranged to affect phase and amplitude of the light emitted by the LEDs to at least partially collimate the light, the second array of niobium pentoxide nanoantennas arranged on a second surface of the substrate opposite from the first surface of the substrate.

22. The mobile device of claim 18, comprising a pre-collimator positioned between the LED array and the metalens in an optical path of light emitted by the array of LEDs.

23. A display system comprising:

a display; ~~and~~

~~the adaptive illumination system of any one of claims 1 through 19 arranged so as to couple light from the array of LEDs into the display.~~

a monolithic array of independently controllable LEDs; and

a metalens spaced apart from the array of LEDs and arranged to couple light from the array of LEDs into the display, the metalens comprising at least a first array of niobium pentoxide nanoantennas arranged to affect phase and amplitude of light emitted by the LEDs to at least partially collimate the light, the metalens being positioned and structurally arranged so that light emitted from different LEDs of the array is directed to corresponding differing predefined far-field regions.

24. The display system of claim 23, wherein each LED has dimensions in a plane of the array of less than or equal to 100 microns.

25. The display system of claim 23, wherein the metalens comprises a substrate, and the first array of niobium pentoxide nanoantennas is arranged on a first surface of the substrate.

26. The display system of claim 25, comprising a second array of niobium pentoxide nanoantennas arranged to affect phase and amplitude of the light emitted by the LEDs to at least partially collimate the light, the second array of niobium pentoxide nanoantennas arranged on a second surface of the substrate opposite from the first surface of the substrate.

27. The display system of claim 23, comprising a pre-collimator positioned between the LED array and the metalens in an optical path of light emitted by the array of LEDs.