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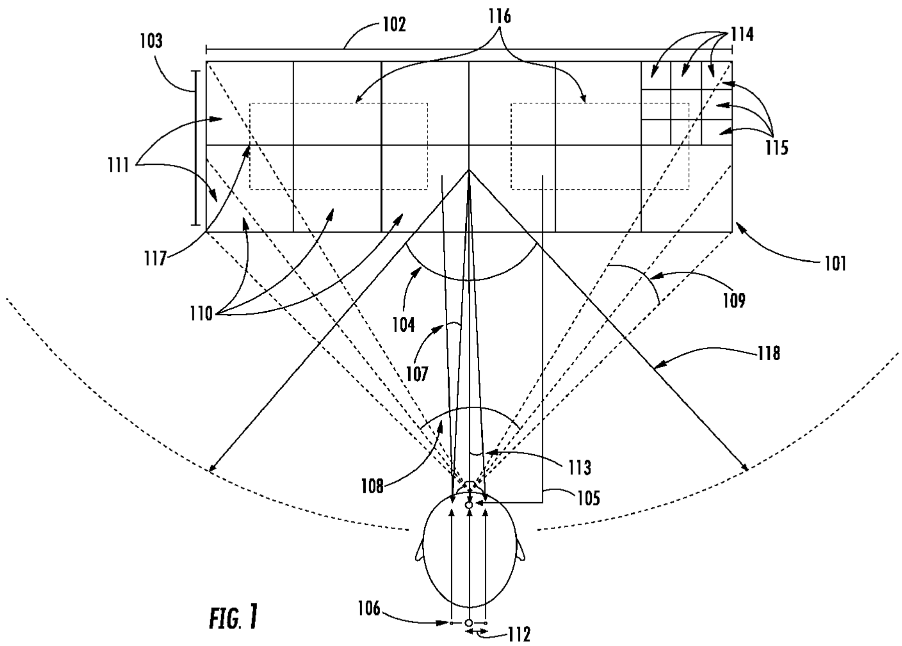

FIG. 1

(57) Abstract: Disclosed embodiments include an energy device having an array of waveguide elements configured to direct energy along a plurality of energy propagation paths through the device, and an energy encoding element operable to limit propagation of energy along the plurality of paths. Energy uninhibited propagation paths may extend through first and second regions of energy locations, the first and seconds regions being overlapping and offsetting, and the energy encoding element may limit propagation of energy through each energy location in the first and second regions to one uninhibited energy propagation path. In an embodiment, the energy encoding element may limit propagation along uninhibited propagation paths through the first region at a first moment in time, and through the second region at a second moment in time. An energy system comprising an energy device subsystem and an energy combiner may be configured to superimpose energy from the energy locations.

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ENCODED ENERGY WAVEGUIDES FOR HOLOGRAPHIC SUPER RESOLUTION

TECHNICAL FIELD

[0001] This disclosure is related to energy directing devices, and specifically to energy waveguides configured to direct energy from encoded apertures from shared energy locations in accordance with a 4D plenoptic function.

BACKGROUND

[0002] The dream of an interactive virtual world within a "holodeck" chamber as popularized by Gene Roddenberry's *Star Trek* and originally envisioned by author Alexander Moszkowski in the early 1900s has been the inspiration for science fiction and technological innovation for nearly a century. However, no compelling implementation of this experience exists outside of literature, media, and the collective imagination of children and adults alike.

SUMMARY

[0003] In an embodiment, an energy device may comprise an array of waveguide elements, wherein the array of waveguide elements may comprise a first side and a second side and may be configured to direct energy therethrough along a plurality of energy propagation paths which extend through a plurality of energy locations on the first side of the array. The energy device may further comprise an energy encoding element operable to limit propagation of energy along the plurality of energy propagation paths.

[0004] In an embodiment, uninhibited energy propagation paths through first and second waveguide elements of the array of waveguide elements may define first and second regions of energy locations, the first and second regions being overlapping and offsetting. An energy encoding element may substantially limit propagation of energy through each energy location in the first and second regions to one uninhibited energy propagation path. The uninhibited energy propagation paths through first and second waveguide elements may form at least a portion of a volumetric energy field defined by a 4D plenoptic function.

[0005] In an embodiment, energy passing through the plurality of energy locations may be encoded in two different energy states, and the energy encoding element may comprise a plurality of first regions and a plurality of second regions, each first region configured to allow energy in the first energy state to pass therethrough substantially uninhibited, and to substantially inhibit propagation of energy in the second energy state, and each second region configured to allow energy in the second energy state to pass therethrough substantially uninhibited, and to substantially inhibit propagation of energy in the first energy state.

In an embodiment, at a first moment in time, the energy encoding element may substantially inhibit energy propagation paths through energy locations in the first region, and the energy encoding element may allow substantially uninhibited energy propagation paths through energy locations in the second region, and at a second moment in time, the energy encoding element may substantially inhibit energy propagation paths through energy locations in the second region, and the energy encoding element may allow substantially uninhibited energy propagation paths through energy locations in the first region.

[0006] In an embodiment, an energy system may comprise an energy device subsystem, comprising a first energy device having a first plurality of energy locations, and a second energy device having a second plurality of energy locations, and an energy combining element configured to relay energy between the energy device subsystem and an energy location surface formed on the energy combining element, wherein the plurality of energy locations may be located on the energy location surface of the energy combining element.

[0007] In an embodiment, the first and second energy devices may be superimposed in a relative orientation such that superimposing an arrangement of the first plurality of energy locations and an arrangement of the second plurality of energy locations result in a third plurality of energy locations at energy location surface, the number of third plurality of energy locations being greater than the sum of the first and second plurality combined for each non-boundary region with resultant energy location sizes that are different than either of the first or second energy locations.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] FIG. 1 is a schematic diagram illustrating design parameters for an energy directing system;

[0009] FIG. 2 is a schematic diagram illustrating an energy system having an active device area with a mechanical envelope;

[0010] FIG. 3 is a schematic diagram illustrating an energy relay system;

[0011] FIG. 4 is a schematic diagram illustrating an embodiment of energy relay elements adhered together and fastened to a base structure;

[0012] FIG. 5A is a schematic diagram illustrating an example of a relayed image through multi-core optical fibers;

[0013] FIG. 5B is a schematic diagram illustrating an example of a relayed image through an optical relay that exhibits the properties of the Transverse Anderson Localization principle;

[0014] FIG. 6 is a schematic diagram showing rays propagated from an energy surface to a viewer;

[0015] FIG. 7 illustrates an embodiment with a field of view as dictated by the energy waveguide element and plurality of energy locations.

[0016] FIG. 8 illustrates an embodiment demonstrating challenging properties for a system with an energy waveguide element having an effective focal length designed to achieve a 120 degree field of view.

[0017] FIG. 9 is an illustration of an embodiment of energy combining element configured to relay energy between energy devices and an energy location surface formed on the energy combining element.

[0018] FIG. 10 illustrates an embodiment of an energy device.

[0019] FIG. 11 illustrates an embodiment of an energy device.

[0020] FIG. 12A-B is an illustration of an embodiment of energy directing device at a first and second moment in time.

[0021] FIG. 13A-B is an illustration of an embodiment of energy directing device at a first and second moment in time.

[0022] FIG. 14A-B is an illustration of an embodiment of energy directing device at a first and second moment in time.

[0023] FIG. 15A-B is an illustration of an embodiment of energy directing device at a first and second moment in time.

[0024] FIG. 16A-B is an illustration of an embodiment of energy directing device at a first and second moment in time.

[0025] FIG. 17A-B is an illustration of an embodiment of energy directing device at a first and second moment in time.

[0026] FIG. 18 is a top down illustration of an exemplary active energy encoding element.

[0027] FIG. 19A is a side view illustration of an energy combiner system.

[0028] FIG. 19B shows a portion of an energy combiner surface in an overhead view.

[0029] FIG. 19C shows a top view of an alternate embodiment of the energy devices.

[0030] FIG. 20 exemplifies an additional embodiment illustrating how one may achieve the same effective pixel density and change in pixel aspect ratio by leveraging anamorphic energy relay elements.

DETAILED DESCRIPTION

[0031] An embodiment of a Holodeck (collectively called “Holodeck Design Parameters”) provide sufficient energy stimulus to fool the human sensory receptors into believing that received energy impulses within a virtual, social and interactive environment are real, providing: 1) binocular disparity without external accessories, head-mounted eyewear, or other peripherals; 2) accurate motion parallax, occlusion and opacity throughout a viewing volume simultaneously for any number of viewers; 3) visual focus through synchronous convergence, accommodation and miosis of the eye for all perceived rays of light; and 4) converging energy wave propagation of sufficient density and resolution to exceed the human sensory “resolution” for vision, hearing, touch, taste, smell, and/or balance.

[0032] Based upon conventional technology to date, we are decades, if not centuries away from a technology capable of providing for all receptive fields in a compelling way as suggested by the Holodeck Design Parameters including the visual, auditory, somatosensory, gustatory, olfactory, and vestibular systems.

[0033] In this disclosure, the terms light field and holographic may be used interchangeably to define the energy propagation for stimulation of any sensory receptor response. While initial disclosures may refer to examples of electromagnetic and mechanical energy propagation through energy surfaces for holographic imagery and volumetric haptics, all forms of sensory receptors are envisioned in this disclosure. Furthermore, the principles disclosed herein for energy propagation along propagation paths may be applicable to both energy emission and energy capture.

[0034] Many technologies exist today that are often unfortunately confused with holograms including lenticular printing, Pepper’s Ghost, glasses-free stereoscopic displays, horizontal parallax displays, head-mounted VR and AR displays (HMD), and other such illusions generalized as “fauxlography.” These technologies may exhibit some of the desired properties of a true holographic display, however, lack the ability to stimulate the human visual sensory response in any way sufficient to address at least two of the four identified Holodeck Design Parameters.

[0035] These challenges have not been successfully implemented by conventional technology to produce a seamless energy surface sufficient for holographic energy propagation. There are various approaches to implementing volumetric and direction multiplexed light field displays including parallax barriers, hogels, voxels, diffractive optics, multi-view projection, holographic diffusers, rotational mirrors, multilayered displays, time sequential displays, head mounted display, etc., however, conventional approaches may involve a compromise on image quality, resolution, angular sampling density, size, cost, safety, frame rate, etc., ultimately resulting in an unviable technology.

[0036] To achieve the Holodeck Design Parameters for the visual, auditory, somatosensory systems, the human acuity of each of the respective systems is studied and understood to propagate energy waves to sufficiently fool the human sensory receptors. The visual system is capable of resolving to approximately 1 arc min, the auditory system may distinguish the difference in placement as little as three degrees, and the somatosensory system at the hands are capable of discerning points separated by 2 - 12mm. While there are various and conflicting ways to measure these acuities, these values are sufficient to understand the systems and methods to stimulate perception of energy propagation.

[0037] Of the noted sensory receptors, the human visual system is by far the most sensitive given that even a single photon can induce sensation. For this reason, much of this introduction will focus on visual energy wave propagation, and vastly lower resolution energy systems coupled within a disclosed energy waveguide surface may converge appropriate signals to induce holographic sensory perception. Unless otherwise noted, all disclosures apply to all energy and sensory domains.

[0038] When calculating for effective design parameters of the energy propagation for the visual system given a viewing volume and viewing distance, a desired energy surface may be designed to include many gigapixels of effective energy location density. For wide viewing volumes, or near field viewing, the design parameters of a desired energy surface may include hundreds of gigapixels or more of effective energy location density. By comparison, a desired energy source may be designed to have 1 to 250 effective megapixels of energy location density for ultrasonic propagation of volumetric haptics or an array of 36 to 3,600 effective energy locations for acoustic propagation of holographic sound depending on input environmental variables. What is important to note is that with a disclosed bidirectional energy surface architecture, all components may be configured to form the appropriate structures for any energy domain to enable holographic propagation.

[0039] However, the main challenge to enable the Holodeck today involves available visual technologies and electromagnetic device limitations. Acoustic and ultrasonic devices are less challenging given the orders of magnitude difference in desired density based upon sensory acuity in the respective receptive field, although the complexity should not be underestimated. While holographic emulsion exists with resolutions exceeding the desired density to encode interference patterns in static imagery, state-of-the-art display devices are limited by resolution, data throughput and manufacturing feasibility. To date, no singular display device has been able to meaningfully produce a light field having near holographic resolution for visual acuity.

[0040] Production of a single silicon-based device capable of meeting the desired resolution for a compelling light field display may not practical and may involve extremely complex fabrication processes beyond the current manufacturing capabilities. The limitation to tiling multiple existing display devices together involves the seams and gap formed by the physical size of packaging, electronics, enclosure, optics and a number of other challenges that inevitably result in an unviable technology from an imaging, cost and/or a size standpoint.

[0041] The embodiments disclosed herein may provide a real-world path to building the Holodeck.

[0042] Example embodiments will now be described hereinafter with reference to the accompanying drawings, which form a part hereof, and which illustrate example embodiments which may be practiced. As used in the disclosures and the appended claims, the terms "embodiment", "example embodiment", and "exemplary embodiment" do not necessarily refer to a single embodiment, although they may, and various example embodiments may be readily combined and interchanged, without departing from the scope or spirit of example embodiments. Furthermore, the terminology as used herein is for the purpose of describing example embodiments only and is not intended to be limitations. In this respect, as used herein, the term "in" may include "in" and "on", and the terms "a," "an" and "the" may include singular and plural references. Furthermore, as used herein, the term "by" may also mean "from", depending on the context. Furthermore, as used herein, the term "if" may also mean "when" or "upon," depending on the context. Furthermore, as used herein, the words "and/or" may refer to and encompass any and all possible combinations of one or more of the associated listed items.

Holographic System Considerations:
Overview of Light Field Energy Propagation Resolution

[0043] Light field and holographic display is the result of a plurality of projections where energy surface locations provide angular, color and intensity information propagated within a viewing volume. The disclosed energy surface provides opportunities for additional information to coexist and propagate through the same surface to induce other sensory system responses. Unlike a stereoscopic display, the viewed position of the converged energy propagation paths in space do not vary as the viewer moves around the viewing volume and any number of viewers may simultaneously see propagated objects in real-world space as if it was truly there. In some embodiments, the propagation of energy may be located in the same energy propagation path but in opposite directions. For example, energy emission and energy capture along an energy propagation path are both possible in some embodiments of the present disclosed.

[0044] FIG. 1 is a schematic diagram illustrating variables relevant for stimulation of sensory receptor response. These variables may include surface diagonal 101, surface width 102, surface height 103, a determined target seating distance 118, the target seating field of view field from the center of the display 104, the number of intermediate samples demonstrated here as samples between the eyes 105, the average adult inter-ocular separation 106, the average resolution of the human eye in arcmin 107, the horizontal field of view formed between the target viewer location and the surface width 108, the vertical field of view formed between the target viewer location and the surface height 109, the resultant horizontal waveguide element resolution, or total number of elements, across the surface 110, the resultant vertical waveguide element resolution, or total number of elements, across the surface 111, the sample distance based upon the inter-ocular spacing between the eyes and the number of intermediate samples for angular projection between the eyes 112. The angular sampling may be based upon the sample distance and the target seating distance 113, the total resolution Horizontal per waveguide element derived from the angular sampling desired 114, the total resolution Vertical per waveguide element derived from the angular sampling desired 115. Device Horizontal is the count of the determined number of discreet energy sources desired 116, and device Vertical is the count of the determined number of discreet energy sources desired 117.

[0045] A method to understand the desired minimum resolution may be based upon the following criteria to ensure sufficient stimulation of visual (or other) sensory receptor response: surface size (e.g., 84" diagonal), surface aspect ratio (e.g., 16:9), seating distance (e.g., 128" from the display), seating field of view (e.g., 120 degrees or +/- 60 degrees about the center of the display), desired intermediate samples at a distance (e.g., one additional propagation path between the eyes), the average inter-ocular separation of an adult (approximately 65mm), and the average resolution of the human eye (approximately 1 arcmin). These example values should be considered placeholders depending on the specific application design parameters.

[0046] Further, each of the values attributed to the visual sensory receptors may be replaced with other systems to determine desired propagation path parameters. For other energy propagation embodiments, one may consider the auditory system's angular sensitivity as low as three degrees, and the somatosensory system's spatial resolution of the hands as small as 2 - 12mm.

[0047] While there are various and conflicting ways to measure these sensory acuities, these values are sufficient to understand the systems and methods to stimulate perception of virtual energy propagation. There are many ways to consider the design resolution, and the below proposed methodology combines pragmatic product considerations with the biological resolving limits of the sensory systems. As will be appreciated by one of ordinary skill in the art, the following overview is a simplification of any such system design, and should be considered for exemplary purposes only.

[0048] With the resolution limit of the sensory system understood, the total energy waveguide element density may be calculated such that the receiving sensory system cannot discern a single energy waveguide element from an adjacent element, given:

- Surface Aspect Ratio = $\frac{Width\ (W)}{Height\ (H)}$
- $Surface\ Horizontal\ Size = Surface\ Diagonal * (\frac{1}{\sqrt{(1+(\frac{H}{W})^2}})$
- $Surface\ Vertical\ Size = Surface\ Diagonal * (\frac{1}{\sqrt{(1+(\frac{W}{H})^2}})$
- $Horizontal\ Field\ of\ View = 2 * \text{atan}\left(\frac{Surface\ Horizontal\ Size}{2 * Seating\ Distance}\right)$
- $Vertical\ Field\ of\ View = 2 * \text{atan}\left(\frac{Surface\ Verticle\ Size}{2 * Seating\ Distance}\right)$
- $Horizontal\ Element\ Resolution = \text{Horizontal FoV} * \frac{60}{Eye\ Resolution}$
- $Vertical\ Element\ Resolution = \text{Vertical FoV} * \frac{60}{Eye\ Resolution}$

[0049] The above calculations result in approximately a 32x18° field of view resulting in approximately 1920x1080 (rounded to nearest format) energy waveguide elements being desired. One may also constrain the variables such that the field of view is consistent for both (u, v) to provide a more regular spatial sampling of energy locations (e.g. pixel aspect ratio). The angular sampling of the system assumes a defined target viewing volume location and additional propagated energy paths between two points at the optimized distance, given:

- $Sample\ Distance = \frac{Inter-Ocular\ Distance}{(Number\ of\ Desired\ Intermediate\ Samples+1)}$
- $Angular\ Sampling = \text{atan}(\frac{Sample\ Distance}{Seating\ Distance})$

[0050] In this case, the inter-ocular distance is leveraged to calculate the sample distance although any metric may be leveraged to account for appropriate number of samples as a given distance. With the above variables considered, approximately one ray per 0.57° may be desired and the total system resolution per independent sensory system may be determined, given:

- $Locations\ Per\ Element(N) = \frac{Seating\ FoV}{Angular\ Sampling}$
- $Total\ Resolution\ H = N * Horizontal\ Element\ Resolution$
- $Total\ Resolution\ V = N * Vertical\ Element\ Resolution$

[0051] With the above scenario given the size of energy surface and the angular resolution addressed for the visual acuity system, the resultant energy surface may desirably include approximately 400k x 225k pixels of energy resolution locations, or 90 gigapixels holographic propagation density. These variables provided are for exemplary purposes only and many other sensory and energy metrology considerations should be considered for the optimization of holographic propagation of energy. In an additional embodiment, 1 gigapixel of energy resolution locations may be desired based upon the input variables. In an additional embodiment, 1,000 gigapixels of energy resolution locations may be desired based upon the input variables.

Current Technology Limitations:

Active Area, Device Electronics, Packaging, and the Mechanical Envelope

[0052] FIG. 2 illustrates a device 200 having an active area 220 with a certain mechanical form factor. The device 200 may include drivers 230 and electronics 240 for powering and interface to the active area 220, the active area having a dimension as shown by the x and y arrows. This device 200 does not take into account the cabling and mechanical structures to drive, power and cool components, and the mechanical footprint may be further minimized by introducing a flex cable into the device 200. The minimum footprint for such a device 200 may also be referred to as a mechanical envelope 210 having a dimension as shown by the M:x and M:y arrows. This device 200 is for illustration purposes only and custom electronics designs may further decrease the mechanical envelope overhead, but in almost all cases may not be the exact size of the active area of the device. In an embodiment, this device 200 illustrates the dependency of electronics as it relates to active image area 220 for a micro OLED, DLP chip or LCD panel, or any other technology with the purpose of image illumination.

[0053] In some embodiments, it may also be possible to consider other projection technologies to aggregate multiple images onto a larger overall display. However, this may come at the cost of greater complexity for throw distance, minimum focus, optical quality, uniform field resolution, chromatic aberration, thermal properties, calibration, alignment, additional size or form factor. For most practical applications, hosting tens or hundreds of these projection sources 200 may result in a design that is much larger with less reliability.

[0054] For exemplary purposes only, assuming energy devices with an energy location density of 3840 x 2160 sites, one may determine the number of individual energy devices (e.g., device 100) desired for an energy surface, given:

- $Devices\ H = \frac{Total\ Resolution\ H}{Device\ Resolution\ H}$
- $Devices\ V = \frac{Total\ Resolution\ V}{Device\ Resolution\ V}$

[0055] Given the above resolution considerations, approximately 105 x 105 devices similar to those shown in FIG. 2 may be desired. It should be noted that many devices consist of various pixel structures that may or may not map to a regular grid. In the event that there are additional sub-pixels or locations within each full pixel, these may be exploited to generate additional resolution or angular density. Additional signal processing may be used to determine how to convert the light field into the correct (u,v) coordinates depending on the specified location of the pixel structure(s) and can be an explicit characteristic of each device that is known and calibrated. Further, other energy domains may involve a different handling of these ratios and device structures, and those skilled in the art will understand the direct intrinsic relationship between each of the desired frequency domains. This will be shown and discussed in more detail in subsequent disclosure.

[0056] The resulting calculation may be used to understand how many of these individual devices may be desired to produce a full resolution energy surface. In this case, approximately 105 x 105 or approximately 11,080 devices may be desired to achieve the visual acuity threshold. The challenge and novelty exists within the fabrication of a seamless energy surface from these available energy locations for sufficient sensory holographic propagation.

Summary of Seamless Energy Surfaces:

Configurations and Designs for Arrays of Energy Relays

[0057] In some embodiments, approaches are disclosed to address the challenge of generating high energy location density from an array of individual devices without seams due to the limitation of mechanical structure for the devices. In an embodiment, an energy propagating relay system may allow for an increase the effective size of the active device area to meet or exceed the mechanical dimensions to configure an array of relays and form a singular seamless energy surface.

[0058] FIG. 3 illustrates an embodiment of such an energy relay system 300. As shown, the relay system 300 may include a device 310 mounted to a mechanical envelope 320, with an energy relay element 330 propagating energy from the device 310. The relay element 330 may be configured to provide the ability to mitigate any gaps 340 that may be produced when multiple mechanical envelopes 320 of the device are placed into an array of multiple devices 310.

[0059] For example, if a device's active area 310 is 20mm x 10mm and the mechanical envelope 32 is 40mm x 20mm, an energy relay element 330 may be designed with a magnification of 2:1 to produce a tapered form that is approximately 20mm x 10mm on a minified end (arrow A) and 40mm x 20mm on a magnified end (arrow B), providing the ability to align an array of these elements 330 together seamlessly without altering or colliding with the mechanical envelope 320 of each device 310. Mechanically, the relay elements 330 may be bonded or fused together to align and polish ensuring minimal seam gap 340 between devices 310. In one such embodiment, it is possible to achieve a seam gap 340 smaller than the visual acuity limit of the eye.

[0060] FIG. 4 illustrates an example of a base structure 400 having energy relay elements 410 formed together and securely fastened to an additional mechanical structure 430. The mechanical structure of the seamless energy surface 420 provides the ability to couple multiple energy relay elements 410, 450 in series to the same base structure through bonding or other mechanical processes to mount relay elements 410, 450. In some embodiments, each relay element 410 may be fused, bonded, adhered, pressure fit, aligned or otherwise attached together to form the resultant seamless energy surface 420. In some embodiments, a device 480 may be mounted to the rear of the relay element 410 and aligned passively or actively to ensure appropriate energy location alignment within the determined tolerance is maintained.

[0061] In an embodiment, the seamless energy surface comprises one or more energy locations and one or more energy relay element stacks comprise a first and second side and each energy relay element stack is arranged to form a singular seamless display surface directing energy along propagation paths extending between one or more energy locations and the seamless display surface, and where the separation between the edges of any two adjacent second sides of the terminal energy relay elements is less than the minimum perceptible contour as defined by the visual acuity of a human eye having better than 20/40 vision at a distance greater than the width of the singular seamless display surface.

[0062] In an embodiment, each of the seamless energy surfaces comprise one or more energy relay elements each with one or more structures forming a first and second surface with a transverse and longitudinal orientation. The first relay surface has an area different than the second resulting in positive or negative magnification and configured with explicit surface contours for both the first and second surfaces passing energy through the second relay surface to substantially fill a +/- 10 degree angle with respect to the normal of the surface contour across the entire second relay surface.

[0063] In an embodiment, multiple energy domains may be configured within a single, or between multiple energy relays to direct one or more sensory holographic energy propagation paths including visual, acoustic, tactile or other energy domains.

[0064] In an embodiment, the seamless energy surface is configured with energy relays that comprise two or more first sides for each second side to both receive and emit one or more energy domains simultaneously to provide bidirectional energy propagation throughout the system.

[0065] In an embodiment, the energy relays are provided as loose coherent elements.

Introduction to Component Engineered Structures:

Disclosed Advances in Transverse Anderson Localization Energy Relays

[0066] The properties of energy relays may be significantly optimized according to the principles disclosed herein for energy relay elements that induce Transverse Anderson Localization. Transverse Anderson Localization is the propagation of a ray transported through a transversely disordered but longitudinally consistent material.

[0067] This implies that the effect of the materials that produce the Anderson Localization phenomena may be less impacted by total internal reflection than by the randomization between multiple-scattering paths where wave interference can completely limit the propagation in the transverse orientation while continuing in the longitudinal orientation.

[0068] Of significant additional benefit is the elimination of the cladding of traditional multi-core optical fiber materials. The cladding is to functionally eliminate the scatter of energy between fibers, but simultaneously act as a barrier to rays of energy thereby reducing transmission by at least the core to clad ratio (e.g., a core to clad ratio of 70:30 will transmit at best 70% of received energy transmission) and additionally forms a strong pixelated patterning in the propagated energy.

[0069] FIG. 5A illustrates an end view of an example of one such non-Anderson Localization energy relay 500, wherein an image is relayed through multi-core optical fibers where pixilation and fiber noise may be exhibited due to the intrinsic properties of the optical fibers. With traditional multi-mode and multi-core optical fibers, relayed images may be intrinsically pixelated due to the properties of total internal reflection of the discrete array of cores where any cross-talk between cores will reduce the modulation transfer function and increase blurring. The resulting imagery produced with traditional multi-core optical fiber tends to have a residual fixed noise fiber pattern similar to those shown in figure 3.

[0070] FIG. 5B, illustrates an example of the same relayed image 550 through an energy relay comprising materials that exhibit the properties of Transverse Anderson Localization, where the relayed pattern has a greater density grain structures as compared to the fixed fiber pattern from figure 5A. In an embodiment, relays comprising randomized microscopic component engineered structures induce Transverse Anderson Localization and transport light more efficiently with higher propagation of resolvable resolution than commercially available multi-mode glass optical fibers.

[0071] There is significant advantage to the Transverse Anderson Localization material properties in terms of both cost and weight, where a similar optical grade glass material, may cost and weigh upwards of 10 to 100-fold more than the cost for the same material generated within an embodiment, wherein disclosed systems and methods comprise randomized microscopic component engineered structures demonstrating significant opportunities to improve both cost and quality over other technologies known in the art.

[0072] In an embodiment, a relay element exhibiting Transverse Anderson Localization may comprise a plurality of at least two different component engineered structures in each of three orthogonal planes arranged in a dimensional lattice and the plurality of structures form randomized distributions of material wave propagation properties in a transverse plane within the dimensional lattice and channels of similar values of material wave propagation properties in a longitudinal plane within the dimensional lattice, wherein localized energy waves propagating through the energy relay have higher transport efficiency in the longitudinal orientation versus the transverse orientation.

[0073] In an embodiment, multiple energy domains may be configured within a single, or between multiple Transverse Anderson Localization energy relays to direct one or more sensory holographic energy propagation paths including visual, acoustic, tactile or other energy domains.

[0074] In an embodiment, the seamless energy surface is configured with Transverse Anderson Localization energy relays that comprise two or more first sides for each second side to both receive and emit one or more energy domains simultaneously to provide bidirectional energy propagation throughout the system.

[0075] In an embodiment, the Transverse Anderson Localization energy relays are configured as loose coherent or flexible energy relay elements.

Considerations for 4D Plenoptic Functions:

Selective Propagation of Energy through Holographic Waveguide Arrays

[0076] As discussed above and herein throughout, a light field display system generally includes an energy source (e.g., illumination source) and a seamless energy surface configured with sufficient energy location density as articulated in the above discussion. A plurality of relay elements may be used to relay energy from the energy devices to the seamless energy surface. Once energy has been delivered to the seamless energy surface with the requisite energy location density, the energy can be propagated in accordance with a 4D plenoptic function through a disclosed energy waveguide system. As will be appreciated by one of ordinary skill in the art, a 4D plenoptic function is well known in the art and will not be elaborated further herein.

[0077] The energy waveguide system selectively propagates energy through a plurality of energy locations along the seamless energy surface representing the spatial coordinate of the 4D plenoptic function with a structure configured to alter an angular direction of the energy waves passing through representing the angular component of the 4D plenoptic function, wherein the energy waves propagated may converge in space in accordance with a plurality of propagation paths directed by the 4D plenoptic function.

[0078] Reference is now made to FIG. 6 illustrating an example of light field energy surface in 4D image space in accordance with a 4D plenoptic function. The figure shows ray traces of an energy surface 600 to a viewer 620 in describing how the rays of energy converge in space 630 from various positions within the viewing volume. As shown, each waveguide element 610 defines four dimensions of information describing energy propagation 640 through the energy surface 600. Two spatial dimensions (herein referred to as x and y) are the physical plurality of energy locations that can be viewed in image space, and the angular components theta and phi (herein referred to as u and v), which is viewed in virtual space when projected through the energy waveguide array. In general, and in accordance with a 4D plenoptic function, the plurality of waveguides (e.g., lenslets) are able to direct an energy location from the x, y dimension to a unique location in virtual space, along a direction defined by the u, v angular component, in forming the holographic or light field system described herein.

[0079] However, one skilled in the art will understand that a significant challenge to light field and holographic display technologies arises from uncontrolled propagation of energy due designs that have not accurately accounted for any of diffraction, scatter, diffusion, angular direction, calibration, focus, collimation, curvature, uniformity, element cross-talk, as well as a multitude of other parameters that contribute to decreased effective resolution as well as an inability to accurately converge energy with sufficient fidelity.

[0080] In an embodiment, an approach to selective energy propagation for addressing challenges associated with holographic display may include energy encoding elements and substantially filling waveguide apertures with near-collimated energy into an environment defined by a 4D plenoptic function.

[0081] In an embodiment, an array of energy waveguides may define a plurality of energy propagation paths for each waveguide element configured to extend through and substantially fill the waveguide element's effective aperture in unique directions defined by a prescribed 4D function to a plurality of energy locations along a seamless energy surface inhibited by one or more elements positioned to limit propagation of each energy location to only pass through a single waveguide element.

[0082] In an embodiment, multiple energy domains may be configured within a single, or between multiple energy waveguides to direct one or more sensory holographic energy propagations including visual, acoustic, tactile or other energy domains.

[0083] In an embodiment, the energy waveguides and seamless energy surface are configured to both receive and emit one or more energy domains to provide bidirectional energy propagation throughout the system.

[0084] In an embodiment, the energy waveguides are configured to propagate non-linear or non-regular distributions of energy, including non-transmitting void regions, leveraging digitally encoded, diffractive, refractive, reflective, grin, holographic, Fresnel, or the like waveguide configurations for any seamless energy surface orientation including wall, table, floor, ceiling, room, or other geometry based environments. In an additional embodiment, an energy waveguide element may be configured to produce various geometries that provide any surface profile and/or tabletop viewing allowing users to view holographic imagery from all around the energy surface in a 360-degree configuration.

[0085] In an embodiment, the energy waveguide array elements may be reflective surfaces and the arrangement of the elements may be hexagonal, square, irregular, semi-regular, curved, non-planar, spherical, cylindrical, tilted regular, tilted irregular, spatially varying and/or multi-layered.

[0086] For any component within the seamless energy surface, waveguide, or relay components may include, but not limited to, optical fiber, silicon, glass, polymer, optical relays, diffractive, holographic, refractive, or reflective elements, optical face plates, energy combiners, beam splitters, prisms, polarization elements, spatial light modulators, active pixels, liquid crystal cells, transparent displays, or any similar materials exhibiting Anderson localization or total internal reflection.

Realizing the Holodeck: Aggregation of Bidirectional Seamless Energy Surface Systems to Stimulate Human Sensory Receptors Within Holographic Environments

[0087] It is possible to construct large-scale environments of seamless energy surface systems by tiling, fusing, bonding, attaching, and/or stitching multiple seamless energy surfaces together forming arbitrary sizes, shapes, contours or form-factors including entire rooms. Each energy surface system may comprise an assembly having a base structure, energy surface, relays, waveguide, devices, and electronics, collectively configured for bidirectional holographic energy propagation, emission, reflection, or sensing.

[0088] In an embodiment, an environment of tiled seamless energy systems are aggregated to form large seamless planar or curved walls including installations comprising up to all surfaces in a given environment, and configured as any combination of seamless, discontinuous planar, faceted, curved, cylindrical, spherical, geometric, or non-regular geometries.

[0089] In an embodiment, aggregated tiles of planar surfaces form wall-sized systems for theatrical or venue-based holographic entertainment. In an embodiment, aggregated tiles of planar surfaces cover a room with four to six walls including both ceiling and floor for cave-based holographic installations. In an embodiment, aggregated tiles of curved surfaces produce a cylindrical seamless environment for immersive holographic installations. In an embodiment, aggregated tiles of seamless spherical surfaces form a holographic dome for immersive Holodeck-based experiences.

[0090] In an embodiment, aggregates tiles of seamless curved energy waveguides provide mechanical edges following the precise pattern along the boundary of energy encoding elements within the energy waveguide structure to bond, align, or fuse the adjacent tiled mechanical edges of the adjacent waveguide surfaces, resulting in a modular and seamless energy waveguide system.

[0091] In a further embodiment of an aggregated tiled environment, energy is propagated bidirectionally for multiple simultaneous energy domains. In an additional embodiment, the energy surface provides the ability to both display and capture simultaneously from the same energy surface with waveguides designed such that light field data may be projected by an illumination source through the waveguide and simultaneously received through the same energy surface. In an additional embodiment, additional depth sensing and active scanning technologies may be leveraged to allow for the interaction between the energy propagation and the viewer in correct world coordinates. In an additional embodiment, the energy surface and waveguide are operable to emit, reflect or converge frequencies to induce tactile sensation or volumetric haptic feedback. In some embodiments, any combination of bidirectional energy propagation and aggregated surfaces are possible.

[0092] In an embodiment, the system comprises an energy waveguide capable of bidirectional emission and sensing of energy through the energy surface with one or more energy devices independently paired with two-or-more-path energy combiners to pair at least two energy devices to the same portion of the seamless energy surface, or one or more energy devices are secured behind the energy surface, proximate to an additional component secured to the base structure, or to a location in front and outside of the FOV of the waveguide for off-axis direct or reflective projection or sensing, and the resulting energy surface provides for bidirectional transmission of energy allowing the waveguide to converge energy, a first device to emit energy and a second device to sense energy, and where the information is processed to perform computer vision related tasks including, but not limited to, 4D plenoptic eye and retinal tracking or sensing of interference within propagated energy patterns, depth estimation, proximity, motion tracking, image, color, or sound formation, or other energy frequency analysis. In an additional embodiment, the tracked positions actively calculate and modify positions of energy based upon the interference between the bidirectional captured data and projection information.

[0093] In some embodiments, a plurality of combinations of three energy devices comprising an ultrasonic sensor, a visible electromagnetic display, and an ultrasonic emitting device are configured together for each of three first relay surfaces propagating energy combined into a single second energy relay surface with each of the three first surfaces comprising engineered properties specific to each device's energy domain, and two engineered waveguide elements configured for ultrasonic and electromagnetic energy respectively to provide the ability to direct and converge each device's energy independently and substantially unaffected by the other waveguide elements that are configured for a separate energy domain.

[0094] In some embodiments, disclosed is a calibration procedure to enable efficient manufacturing to remove system artifacts and produce a geometric mapping of the resultant energy surface for use with encoding/decoding technologies as well as dedicated integrated systems for the conversion of data into calibrated information appropriate for energy propagation based upon the calibrated configuration files.

[0095] In some embodiments, additional energy waveguides in series and one or more energy devices may be integrated into a system to produce opaque holographic pixels.

[0096] In some embodiments, additional waveguide elements may be integrated comprising energy encoding elements, beam-splitters, prisms, active parallax barriers or polarization technologies in order to provide spatial and/or angular resolutions greater than the diameter of the waveguide or for other super-resolution purposes.

[0097] In some embodiments, the disclosed energy system may also be configured as a wearable bidirectional device, such as virtual reality (VR) or augmented reality (AR). In other embodiments, the energy system may include adjustment optical element(s) that cause the displayed or received energy to be focused proximate to a determined plane in space for a viewer. In some embodiments, the waveguide array may be incorporated to holographic head-mounted-display. In other embodiments, the system may include multiple optical paths to allow for the viewer to see both the energy system and a real-world environment (e.g., transparent holographic display). In these instances, the system may be presented as near field in addition to other methods.

[0098] In some embodiments, the transmission of data comprises encoding processes with selectable or variable compression ratios that receive an arbitrary dataset of information and metadata; analyze said dataset and receive or assign material properties, vectors, surface IDs, new pixel data forming a more sparse dataset, and wherein the received data may comprise: 2D, stereoscopic, multi-view, metadata, light field, holographic, geometry, vectors or vectorized metadata, and an encoder/decoder may provide the ability to convert the data in real-time or off-line comprising image processing for: 2D; 2D plus depth, metadata or other vectorized information; stereoscopic, stereoscopic plus depth, metadata or other vectorized information; multi-view; multi-view plus depth, metadata or other vectorized information; holographic; or light field content; through depth estimation algorithms, with or without depth metadata; and an inverse ray tracing methodology appropriately maps the resulting converted data produced by inverse ray tracing from the various 2D, stereoscopic, multi-view, volumetric, light field or holographic data into real world coordinates through a characterized 4D plenoptic function. In these embodiments, the total data transmission desired may be multiple orders of magnitudes less transmitted information than the raw light field dataset.

<u>Energy Inhibiting Encoded Waveguides for Super Resolution in Holographic Systems</u>

[0099] Holographic and plenoptic 4D systems will suffer from significant angular artifacts given mismatch between the total angular distribution of propagated paths through the waveguide aperture and the viewing volume of an energy directing system. In an uncontrolled system, paths from energy waveguide elements may propagate to regions outside of the predetermined array of energy locations defining the angular distribution of the system when an effective waveguide aperture within an array only comprise the idealized chief ray angle for a given waveguide function, but may not actually be limited to that field of view as energies continue to propagate off-axis beyond the idealized chief ray angle of the waveguide element. Without appropriate consideration for the selective energy propagation for a waveguide array, energy propagation paths from the energy locations allocated for adjacent waveguides may compromise the energy directing system performance.

[00100] FIG. 7 illustrates an embodiment 700 with a field of view 702 as dictated by the energy waveguide element 704 and plurality of energy locations 706 to define the effective angular distribution of the waveguide element 704, and the associated out of viewing volume zone 708. A viewer 710 viewing energy waveguide element 704 along ray 712 will incorrectly view energy location 714, which may not direct the appropriate energy information to viewer 710.

[00101] To address a wider angular distribution of propagation paths to accommodate the off-axis viewer from FIG. 7, a decreased effective waveguide element may be explored. For a chief ray angle distribution of 120 degrees, this would result in approximately an effective f/.6 aperture. Anything below an f/1.4 becomes increasingly more challenging depending on the design of the energy waveguide element. FIG. 8 illustrates an embodiment 800 demonstrating challenging properties for a system with an energy waveguide element 802 having an effective focal length 804 designed to achieve a 120 degree field of view 806.

[00102] FIG. 8 illustrates an idealized waveguide energy propagation angular distribution that does not consider the propagation through the effective aperture of the waveguide element. As disclosed herein, energy encoding elements for selective propagation of energy through waveguide arrays to inhibit off-axis energy propagation paths may be required for any energy directing system design.

[00103] In an embodiment, an energy encoding element may be positioned to limit propagation of energy along a portion of the energy propagation paths. Additionally, the energy encoding element may comprise at least one numerical aperture, and may comprise a baffle structure. In an embodiment, the structure of the energy encoding element may be configured to limit an angular extent of energy propagation thereby.

[00104] As a further extension of the energy encoding elements, comprises systems providing for spatiotemporal super-resolution to increase both effective focal length with retaining the identical extended field of view through overlapping spatial, temporal, or spatiotemporal energy locations with energy encoding elements by effectively converting the inhibiting aspect of the element into an energy encoding methodology through a specified encoding between at least a portion of a waveguide aperture and an energy encoding element. Collectively the pairing within the energy directing system to spatially, temporally, spatiotemporally, or otherwise, will be referred to as an energy encoding element, and the collection of energy encoding elements comprise an energy encoding system.

Energy Encoding Devices through Energy Retaining Combiners and Energy Retaining Component Engineered Structures

[00105] Through the use of a novel approach to energy relay devices, in an embodiment of an energy encoding element providing for angular super-resolution, polarization or energy state retaining energy combiners are disclosed through a system comprising a plurality of polarization retaining energy combiners or polarization retaining component engineered structures forming energy combiners exhibiting Transverse Anderson Localization. Through this system, it is possible to directly or indirectly encode a plurality of energy locations and retain the energy encoding state through the energy relay path and through the singular seamless energy surface. In an embodiment, a plurality of encoding energy paths along the energy combiner is possible. In another embodiment, 4 encoded energy paths are provided. In another embodiment, 8 encoded energy paths are provided.

[00106] In an embodiment of the energy encoding relay device, a two-state polarization system (e.g. horizontal and vertical, or clockwise and counter-clockwise) is provided to polarize each energy waveguide element or region of each energy waveguide element and propagate two or more overlapping energy location regions simultaneously substantially inhibiting the propagation of stray paths, wherein each propagating path is inhibited to a single energy waveguide element or portion thereof.

[00107] In an embodiment, an energy device may comprise an energy combining element configured to relay energy between a plurality of energy devices and an energy location surface formed on the energy combining element, wherein the plurality of energy locations are located on the energy location surface of the energy combining element, and further wherein energy propagating through different energy devices are relayed through interlaced energy locations on the energy location surface. In an embodiment, the energy combining element may comprise a plurality of energy structures exhibiting transverse Anderson localization. In an embodiment, the energy combining element may comprise a plurality of encoded energy retaining optical fibers, or encoded energy retaining component engineered structures forming energy relay elements exhibiting Transverse Anderson Localization. In an embodiment, energy at the interlaced or woven energy locations may have alternating energy states. In an embodiment, the alternating energy states may be different polarization states. In an embodiment, the energy combiner comprises an energy encoding element on the relayed energy surface.

[00108] The energy combiners, the polarized plurality of energy locations, the polarization states retained through the energy location surface, and the polarized energy waveguide elements may all combine to result in two completely discreet and overlapping energy location regions. In an embodiment, a polarization film may be applied to the energy waveguide element substrate, built into the energy waveguide element directly, placed above, below or at the center of the array of energy waveguide elements as appropriate for the waveguide element functions and polarized energy encoding systems.

[00109] FIG. 9 is an illustration of an embodiment of energy combining element 900 which illustrates this approach. Energy combining element 900 is configured to relay energy between energy devices 902 and 904 and an energy location surface 906 formed on the energy combining element 900. A plurality of energy locations 908 are located on the energy location surface 906, and energy propagating through energy combining element 900 is relayed through interlaced energy locations 910, 912 on the energy location surface 906 having orthogonal polarization states 914, 916.

[00110] In an embodiment, the energy encoding element may be located on the second side of the array of waveguide elements.

[00111] In an embodiment, the energy encoding element may be located on the first side between the plurality of energy locations and the array of waveguide elements.

[00112] In an embodiment, it is possible to leverage active energy encoding elements to further extend the ability to view multiple simultaneous energy location regions of the singular seamless energy surface.

Passive Energy Encoding Systems for Super Resolution in Holographic Systems

[00113] In an embodiment, an energy device may comprise an array of waveguide elements, wherein the array of waveguide elements may comprise a first side and a second side and may be configured to direct energy therethrough along a plurality of energy propagation paths which extend through a plurality of energy locations on the first side of the array. The energy device may further comprise an energy encoding element operable to limit propagation of energy along the plurality of energy propagation paths.

[00114] In an embodiment, uninhibited energy propagation paths through first and second waveguide elements of the array of waveguide elements may define first and second regions of energy locations, the first and second regions being overlapping and offsetting. An energy encoding element may substantially limit propagation of energy through each energy location in the first and second regions to one uninhibited energy propagation path. The uninhibited energy propagation paths through first and second waveguide elements may form at least a portion of a volumetric energy field defined by a 4D plenoptic function.

[00115] In an embodiment, energy passing through the plurality of energy locations may be encoded in two different energy states, and the energy encoding element may comprise an energy encoding element comprising a plurality of first regions and a plurality of second regions, each first region configured to allow energy in the first energy state to pass therethrough substantially uninhibited, and to substantially inhibit propagation of energy in the second energy state, and each second region configured to allow energy in the second energy state to pass therethrough substantially uninhibited, and to substantially inhibit propagation of energy in the first energy state.

[00116] In an embodiment, the energy encoding element may comprise an energy polarizing element. In an embodiment, the different energy states may comprise first and second polarization states, and the energy encoding element may comprise an energy polarizing filter.

[00117] In an embodiment, the energy encoding element may comprise an energy polarizer, such as a linear polarizer; a circular polarizer; or an energy modulation device.

[00118] In an embodiment, the first plurality of regions of the energy encoding element may each comprise an energy polarizing element having a first optical axis, and the second plurality of regions of the energy encoding element may each comprise an energy polarizing element having a second optical axis.

[00119] In an embodiment, the energy locations in the first and second regions may be interlaced or woven by energy encoding states.

[00120] In an embodiment, the energy locations in the first and second regions may be grouped and interlaced or woven by energy encoding states.

[00121] In an embodiment, the plurality of first regions and the plurality of second regions of the energy encoding element may cooperate to define a region of an aperture for each waveguide element.

[00122] FIG. 10 illustrates an embodiment of an energy device 1000. Energy device 1000 comprises an array of waveguide elements 1002, further comprising a first side 1004 and a second side 1006, and configured to direct energy therethrough along a plurality of energy propagation paths 1008 which extend through a plurality of energy locations 1010 on the first side 1004 of the array 1002. Device 1000 further comprises an energy encoding element 1012 operable to limit propagation of energy along the plurality of energy propagation paths 1008. Uninhibited propagation paths 1014, 1016 through first and second waveguide elements 1018, 1020 define first and second regions 1022, 1024 of energy locations, the first and second regions 1022, 1024 being overlapping and offsetting. The energy encoding element 1012 may substantially limit propagation of energy through each energy location in the first and second regions 1022, 1024 to one of uninhibited energy propagation paths 1014 or 1016. The uninhibited propagation paths 1014, 1016 through first and second waveguide elements 1018, 1020 may form at least a portion of a volumetric energy field defined by a 4D plenoptic function. In device 1000, the plurality of energy locations 1010 are passively encoded into a first passive encoding state 1026 or a second passive encoding state 1028, such that the energy locations in the first and second regions 1022, 1024 are interlaced or woven by energy encoding state. The energy encoding element 1012 comprises an encoding comprising first region 1030 configured to allow energy in first state 1026 to pass therethrough and to inhibit energy in second state 1028, and a second region 1032, configured to allow energy in second state 1028 to pass therethrough and to inhibit energy in first state 1026. First region 1030 of energy encoding element 1012 forms an aperture 1034 of waveguide element 1018, and second region 1032 of energy encoding element 1012 forms an aperture 1036 of waveguide element 1020.

[00123] In an embodiment, the plurality of first regions and the plurality of second regions of the energy encoding element may cooperate to define a plurality of apertures for each waveguide element.

[00124] FIG. 11 illustrates an embodiment of an energy device 1100. In energy device 1100, a first region 1102 and a second region 1104 of energy encoding element 1106 form a first aperture region 1108 and a second aperture region 1110 of waveguide element 1112. Third region 1114 and fourth region 1116 of energy encoding element 1106 form a first aperture region 1118 and a second aperture region 1120 of waveguide element 1122.

Active and Hybrid Energy Encoding Systems for Super Resolution in Holographic Systems

[00125] Figs. 10-11 provide for techniques that may not utilize active electronics to enact the encoding of the energy inhibiting methodologies. This is advantageous to provide for the ability to aggregate multiple super resolution systems together given passive components may not exhibit a mechanical envelope to conflict with the aggregation of multiple devices. However, it additionally provides for effectively half of the potential spatial resolution in any such overlapping interlaced or woven configuration in consideration of the angular sampling which is divided by the number of encoding states within the system. In an additional embodiment, an active energy encoding system is disclosed comprising temporal encoding elements to further extend the capabilities to propagate multiple simultaneous energy location regions of the singular seamless energy surface with potentially higher spatial resolutions.

[00126] In an embodiment, uninhibited energy propagation paths through first and second waveguide elements of the array of waveguide elements may define first and second regions of energy locations, the first and second regions being overlapping and offsetting. At a first moment in time, the energy encoding element may substantially inhibit energy propagation paths through energy locations in the first region, and the energy encoding element may allow substantially uninhibited energy propagation paths through energy locations in the second region. At a second moment in time, the energy encoding element may substantially inhibit energy propagation paths through energy locations in the second region, and the energy encoding element may allow substantially uninhibited energy propagation paths through energy locations in the first region. Temporally aggregated uninhibited energy propagation paths through first and second waveguide elements may form at least a portion of a volumetric energy field defined by a 4D plenoptic function.

[00127] In an embodiment, the energy encoding element may comprise an active encoding system configured to switch between at least a first state and a second state, wherein, when driven to the first state, the active encoding element is configured to form a first set of apertures, and when driven to the second state, the active encoding element is configured to form a second set of apertures. In an embodiment, the first and second sets of apertures may be formed by active encoding elements with binary values for transmittance or absorption of a specified energy. In an embodiment, the active encoding elements may comprise transparent pixel arrays. In an embodiment, the active encoding elements may comprise active parallax barriers. In an embodiment, the active parallax barriers may comprise shutters.

[00128] FIG. 12A is an illustration of an embodiment of energy directing device 1200 at a first moment in time and FIG. 12B is an illustration of an energy directing device 1200 at a second moment in time. Energy directing device 1200 comprises active encoding element 1202, which further comprises first and second regions 1204, 1206. At the first moment in time, region 1204 is configured to inhibit energy propagation from energy locations 1212 along energy propagation paths 1208 through waveguide element 1214, while region 1206 is configured to allow energy propagation from energy locations 1212 along energy propagation paths 1210 through waveguide element 1216. At the second moment in time, region 1204 is configured to allow energy propagation from energy locations 1212 along energy propagation paths 1204 through waveguide element 1214, while region 1206 is configured to inhibit energy propagation from energy locations 1212 along energy propagation paths 1208 through waveguide element 1216. It should be noted that in embodiment 1200, there is only one encoding element, that being active encoding element 1202.

[00129] In an embodiment, the one or more active energy encoding elements may be an energy polarization switch, an energy bandpass switch, or an energy modulation device.

[00130] In an embodiment, the one or more passive energy encoding elements may be an energy polarization filter, an energy bandpass filter, or an energy waveguide.

[00131] In an embodiment, the one or more active energy encoding elements may encode energy into different energy states and the one or more passive energy encoding elements may filter energy based on the energy states.

[00132] In an embodiment, the one or more active energy encoding elements may temporally encode energy at a contiguous group of energy locations into different energy states.

[00133] FIG. 13A is an illustration of an embodiment of an energy device 1300 at a first moment in time. Energy device 1300 comprises energy encoding element 1302, which is a passive energy encoding element and which, at a first moment in time, in combination with active energy encoding element 1318, substantially inhibits energy propagation paths 1304 through energy locations in a first region 1306, and allows substantially uninhibited energy propagation paths 1308 through energy locations in a second region 1310, the first and second regions 1306, 1310 being overlapping and offsetting.

[00134] FIG. 13B is an illustration of an embodiment of an energy device 1300 at a second moment in time. At the second moment in time, in combination with active energy encoding element 1318, energy encoding element 1302 substantially inhibits energy propagation paths 1308 through energy locations in second region 1310, and allows substantially uninhibited energy propagation paths 1304 through energy locations in first region 1306.

[00135] Referring to FIG. 13A and FIG. 13B, temporally aggregating uninhibited energy propagation paths 1304 and 1308 through first and second waveguide elements 1312, 1314 form a portion of a volumetric energy field defined by a 4D plenoptic function. Energy device 1300 further comprises an active energy encoding element 1318, which is configured to temporally encode energy at contiguous group of energy locations 1316 into different encoding states at first and second moments in time.

[00136] Of specific note, active energy encoding element 1318 provides for a single state across the plurality of energy locations 1316 and in conjunction with passive energy encoding element 1302 that is divided into encoding regions, substantially inhibits energy propagation paths through the respective waveguides within the system, and through temporal aggregation produce an effective significant increase in both resolution and angular distribution of energy propagation paths.

[00137] In an embodiment, the one or more active energy encoding elements may temporally encode energy at interlaced or woven energy locations into different energy states.

[00138] FIG. 14A is an illustration of an embodiment of energy directing device 1400 at a first moment in time and FIG. 14B is an illustration of an energy directing device 1400 at a second moment in time. Energy device 1400 comprises active energy encoding element 1402, which is configured to temporally encode energy at interlaced or woven energy locations 1404 into alternating first and second encoding states 1406, 1408 at first and second moments in time.

[00139] In an embodiment, the one or more passive energy encoding elements may encode energy into different energy states and the one or more active energy encoding elements may selectively direct energy based on the energy states.

[00140] In an embodiment, the one or more passive energy encoding elements may encode energy into different energy states at interlaced energy locations.

[00141] FIG. 15A is an illustration of an embodiment of an energy directing device 1500 at a first moment in time and FIG. 15B is an illustration of an embodiment of an energy directing device 1500 at a second moment in time. Energy device 1500 comprises a passive energy encoding element 1502 which encodes energy from energy locations 1504 into an interlaced first and second encoded state 1506, 1508. Energy device 1500 further comprises an array of active energy encoding elements 1510 which selectively direct energy from energy locations 1504 based on the encoded state of the energy.

[00142] In an embodiment, the first and second sets of apertures may be formed such that a plurality of apertures are formed for each waveguide element, and wherein the energy encoding element further comprises a split aperture energy encoding element configured to limit propagation of energy along the plurality of energy propagation paths through the plurality of apertures for each waveguide element.

[00143] In an embodiment, the first and second sets of apertures may be formed such that a plurality of apertures or aperture regions are formed for each waveguide element, and wherein energy is directed through the plurality of apertures for each waveguide element temporally.

[00144] FIG. 16A is an illustration of an embodiment of energy device 1600 at a first moment in time and FIG. 16B is an illustration of an embodiment of energy device 1600 at a second moment in time. Energy device 1600 comprises an active energy encoding element 1602 and a second active energy encoding element 1614 offset from the first, and further comprising a third passive energy encoding element 1616 to encode the interlaced or woven energy locations. At the first moment in time, energy encoding element 1602 and 1614 form a first region 1604 and a second region 1606, such that the first waveguide element 1608 is divided into first and second aperture regions 1610, 1612. At the second moment in time, regions 1604and 1606 are switched, and as a result, aperture regions 1610 and 1612 are also switched. The pair of active energy encoding elements 1602 and 1614 are provided in conjunction with passive energy encoding element 1616 in order to provide substantially filled aperture regions that inhibit energy propagation through other adjacent aperture regions.

[00145] FIG. 17A is an illustration of an embodiment of energy device 1700 at a first moment in time and FIG. 17B is an illustration of an embodiment of energy device 1700 at a second moment in time. Energy device 1700 comprises a passive energy encoding element 1702, and a second passive energy encoding element 1714, offset from the first, which passively encode a first region 1704, and a second region 1706, and a third active energy encoding element 1716 which, at the first moment in time, encodes the interlaced or woven energy locations, such that first waveguide element 1708 is divided into first and second aperture regions 1710, 1712. At the second moment in time, the active energy encoding element 1716 switches the encoding of the interlaced or woven energy locations, switching which aperture region 1710, 1712 energy through the energy locations may propagate through substantially uninhibited. The pair of passive energy encoding elements 1702 and 1714 are provided in conjunction with active energy encoding elements 1716 in order to provide substantially filled aperture regions that inhibit energy propagation through other adjacent aperture regions.

[00146] FIG. 18 is a top down illustration of an exemplary active energy encoding element 1800 wherein the waveguide array and the active energy encoding system are configured such that a first waveguide element aperture 1802 is subdivided into 9 regions 1802A-I, forming a 3x3 grid, each of the 9 regions encoded to propagate energy 1808 from the energy locations 1804 ,and wherein the 9 regions are temporally divided into 9 sequential moments in time 1806 such that energy 1808 may propagate through a different region 1802A-I at each sequential moment in time 1806. For any given desired system refresh rate, the energy devices, the energy directing surface, the energy encoding elements each will operate at 9 times the effective refresh speeds in order to direct energy to each of the nine regions sequentially, and wherein all other waveguide elements and active energy encoding elements are configured to coordinate in a similar pattern to propagate energy paths from the energy locations not propagated at any illustrated time interval such that each of the energy locations are propagated cumulatively.

[00147] In an additional embodiment, waveguide elements are configured to exhibit different angular propagation angles along the x-axis and y-axis. In an additional embodiment, the angular difference is 2x greater in the x-axis. In an additional embodiment, the angular difference is 2x greater in the y-axis. In an additional embodiment, the angular difference is 3x greater in the x-axis. In an additional embodiment, the angular difference is 3x greater in the y-axis.

[00148] In a further embodiment, the energy encoding element is configured in coordination with the waveguide element such that the energy encoding functions are applied for active or passive encoding with and of the same angular distribution along the x-axis and the y-axis, greater angular distribution along the x-axis, greater angular distribution along the y-axis, or greater angular distribution about an arbitrary axis.

[00149] For the avoidance of doubt, any value of sequential sampling may be performed and achieved, as long as the requirements of the equations and systems are met.

[00150] An additional embodiment places the active encoding element below the array of energy waveguide elements.

[00151] An additional embodiment places the active encoding elements at the center of the array of energy waveguide elements.

Energy Combiners for Sub-Pixel Super Resolution

[00152] In an embodiment, energy combiners may allow the ability to two or more energy devices determined by the number of segments from the energy waveguide element and align the pixel structures such that they are offset by a value that is a pixel divided by the number of segments from each other along x and y-axis, or with energy devices offset by the appropriate proportion on a single axis alone in order to produce the substantially identical overlaid virtual energy location structures. It is to be appreciated that while the discussion herein may refer to pixels and pixel structures, these elements in some embodiments may refer to energy input or out units in an energy device.

[00153] In an embodiment, an energy system may comprise an energy device subsystem, comprising a first energy device having a first plurality of energy locations and a second energy device having a second plurality of energy locations, and an energy combining element configured to relay energy between the energy device subsystem and an energy location surface formed on the energy combining element, wherein the plurality of energy locations are located on the energy location surface of the energy combining element.

[00154] In an embodiment, the first and second energy devices may be superimposed in a relative orientation such that superimposing an arrangement of the first plurality of energy locations and an arrangement of the second plurality of energy locations results in a third plurality of energy locations at the energy location surface, the number of third plurality of energy locations being greater than the sum of the first and second plurality combined for each non-boundary region with resultant energy location sizes that are smaller or different than either of the first or second energy locations.

[00155] In an embodiment, the first plurality of energy locations may comprise energy locations defined in rectangular regions.

[00156] In an embodiment, both the first and second plurality of energy locations may comprise energy locations defined in rectangular regions.

[00157] In an embodiment, the first plurality of energy locations may comprise energy locations defined in square regions.

[00158] In an embodiment, the first plurality of energy locations may comprise energy locations defined in rectangular regions, and the second plurality energy location may comprise energy locations defined as any of square, round, rectangle, triangular, hexagonal, delta structure, regular or non-regular regions.

[00159] With this approach, taking for example two segments, a second energy device may be offset from a first energy device reference pixel by .5 pixel. By performing this sub-pixel shift, it is possible to produce higher effective resolution through resultant sub-pixel structure.

[00160] Alternative sub-pixel structures may be leveraged. In an embodiment, rectangular pixels are overlaid and rather than performing a sub-pixel offset, one energy devices is rotated 90 degrees in respect to the other and mounted to the second surface of the energy combiner such that a regular grid of sub-pixel squares forms from the two orthogonal rectangular structures and results in higher overall effective resolution than the two devices alone.

[00161] FIG. 19A is a side view illustration of an energy combiner system 1900 which demonstrates the approach of overlaid pixel structures. Energy combiner 1900 is used in conjunction with two offset energy devices 1902, 1904. Energy combiner 1900 combines energy from energy devices 1902, 1904 overtop of each other in an offset orientation in order to form sub-pixel structures on energy combiner surface 1906. FIG. 19B shows a portion of energy combiner surface 1906 in an overhead view. Pixel structures 1908 from energy devices 1902 are overlaid with pixel structures 1910 from energy device 1904, forming a number of subpixels 1912. FIG. 19C shows a top view of an alternate embodiment of the energy devices 1902, 1904, and the resultant energy combiner surface 1906, and illustrates how rectangular pixel structures 1914, when combined in an orthogonal orientation, may result in square sub-pixel structures 1916. The square sub-pixel structures 1916 may allow a 3x increase in pixel density when aggregated through the energy combiner 1900 with higher resolution than the two energy devices 1902, 1904 alone.

[00162] In a further embodiment, the energy combiner with greater than two first surfaces is used to increase effective pixel density beyond the first embodiment disclosed.

[00163] In an additional embodiment, the energy combiner is leveraged with passive or active energy encoding systems.

[00164] FIG. 20 exemplifies an additional embodiment illustrating how one may achieve the same effective pixel density and change in pixel aspect ratio by leveraging anamorphic energy relay elements wherein an input rectangular pixel structure 2002 is applied to an anamorphic energy relay element 2004 at the bottom surface 2006, wherein the anamorphic energy relay provides for

a 3:1 anamorphic squeeze, as exemplified by the rectangular form of the energy element surface, and applied in the opposite orientation of the rectangular pixel structure resulting in a the viewed result at the top of the energy relay surface 2008 now comprises 12 square pixels when the original structure 2002 was rectangular.

[00165] In an additional embodiment, the energy combiner comprises arbitrary magnification and arbitrary pixel structure.

[00166] In an additional embodiment, the energy combiner is leveraged in the same anamorphic configuration.

[00167] In an additional embodiment, the energy combiner is leveraged with passive or active energy encoding systems.

[00168] While various embodiments in accordance with the principles disclosed herein have been described above, it should be understood that they have been presented by way of example only, and are not limiting. Thus, the breadth and scope of the invention(s) should not be limited by any of the above-described exemplary embodiments, but should be defined only in accordance with the claims and their equivalents issuing from this disclosure. Furthermore, the above advantages and features are provided in described embodiments, but shall not limit the application of such issued claims to processes and structures accomplishing any or all of the above advantages.

[00169] It will be understood that the principal features of this disclosure can be employed in various embodiments without departing from the scope of the disclosure. Those skilled in the art will recognize, or be able to ascertain using no more than routine experimentation, numerous equivalents to the specific procedures described herein. Such equivalents are considered to be within the scope of this disclosure and are covered by the claims.

[00170] Additionally, the section headings herein are provided for consistency with the suggestions under 37 CFR 1.77 or otherwise to provide organizational cues. These headings shall not limit or characterize the invention(s) set out in any claims that may issue from this disclosure. Specifically, and by way of example, although the headings refer to a "Field of Invention," such claims should not be limited by the language under this heading to describe the so-called technical field. Further, a description of technology in the "Background of the Invention" section is not to be construed as an admission that technology is prior art to any invention(s) in this disclosure. Neither is the "Summary" to be considered a characterization of the invention(s) set forth in issued claims. Furthermore, any reference in this disclosure to "invention" in the singular should not be used to argue that there is only a single point of novelty in this disclosure. Multiple inventions may be set forth according to the limitations of the multiple claims issuing from this disclosure, and such claims accordingly define the invention(s), and their equivalents, that are protected thereby. In all instances, the scope of such claims shall be considered on their own merits in light of this disclosure, but should not be constrained by the headings set forth herein.

[00171] The use of the word “a” or “an” when used in conjunction with the term “comprising” in the claims and/or the specification may mean “one,” but it is also consistent with the meaning of “one or more,” “at least one,” and “one or more than one.” The use of the term “or” in the claims is used to mean “and/or” unless explicitly indicated to refer to alternatives only or the alternatives are mutually exclusive, although the disclosure supports a definition that refers to only alternatives and “and/or.” Throughout this application, the term “about” is used to indicate that a value includes the inherent variation of error for the device, the method being employed to determine the value, or the variation that exists among the study subjects. In general, but subject to the preceding discussion, a numerical value herein that is modified by a word of approximation such as “about” may vary from the stated value by at least ±1, 2, 3, 4, 5, 6, 7, 10, 12 or 15%.

[00172] As used in this specification and claim(s), the words “comprising” (and any form of comprising, such as “comprise” and “comprises”), “having” (and any form of having, such as “have” and “has”), “including” (and any form of including, such as “includes” and “include”) or “containing” (and any form of containing, such as “contains” and “contain”) are inclusive or open-ended and do not exclude additional, unrecited elements or method steps.

[00173] Words of comparison, measurement, and timing such as “at the time,” “equivalent,” “during,” “complete,” and the like should be understood to mean “substantially at the time,” “substantially equivalent,” “substantially during,” “substantially complete,” etc., where “substantially” means that such comparisons, measurements, and timings are practicable to accomplish the implicitly or expressly stated desired result. Words relating to relative position of elements such as “near,” “proximate to,” and “adjacent to” shall mean sufficiently close to have a material effect upon the respective system element interactions. Other words of approximation similarly refer to a condition that when so modified is understood to not necessarily be absolute or perfect but would be considered close enough to those of ordinary skill in the art to warrant designating the condition as being present. The extent to which the description may vary will depend on how great a change can be instituted and still have one of ordinary skilled in the art recognize the modified feature as still having the required characteristics and capabilities of the unmodified feature.

[00174] The term “or combinations thereof” as used herein refers to all permutations and combinations of the listed items preceding the term. For example, “A, B, C, or combinations thereof is intended to include at least one of: A, B, C, AB, AC, BC, or ABC, and if order is important in a particular context, also BA, CA, CB, CBA, BCA, ACB, BAC, or CAB. Continuing with this example, expressly included are combinations that contain repeats of one or more item or term, such as BB, AAA, AB, BBC, AAABCCCC, CBBAAA, CABABB, and so forth. The skilled artisan will understand that typically there is no limit on the number of items or terms in any combination, unless otherwise apparent from the context.

[00175] All of the compositions and/or methods disclosed and claimed herein can be made and executed without undue experimentation in light of the present disclosure. While the compositions and methods of this disclosure have been described in terms of preferred embodiments, it will be apparent to those of skill in the art that variations may be applied to the compositions and/or methods and in the steps or in the sequence of steps of the method described herein without departing from the concept, spirit and scope of the disclosure. All such similar substitutes and modifications apparent to those skilled in the art are deemed to be within the spirit, scope and concept of the disclosure as defined by the appended claims.

What is claimed is:

1. An energy device comprising:

an array of waveguide elements, wherein the array of waveguide elements comprises a first side and a second side, the array of waveguide elements being configured to direct energy therethrough along a plurality of energy propagation paths which extend through a plurality of energy locations on the first side of the array; and

an energy encoding element operable to limit propagation of energy along the plurality of energy propagation paths;

wherein uninhibited energy propagation paths through first and second waveguide elements of the array of waveguide elements define first and second regions of energy locations, the first and second regions being overlapping and offsetting; and further wherein, the energy encoding element substantially limits propagation of energy through each energy location in the first and second regions to one uninhibited energy propagation path;

wherein the uninhibited energy propagation paths through first and second waveguide elements form at least a portion of a volumetric energy field defined by a 4D plenoptic function.

2. The energy device of claim 1, wherein energy passing through the plurality of energy locations is encoded in two different energy states; and

wherein the energy encoding element comprises an energy element, the energy element comprising a plurality of first regions and a plurality of second regions, each first region configured to allow energy in the first energy state to pass therethrough substantially uninhibited, and to substantially inhibit propagation of energy in the second energy state, and each second region configured to allow energy in the second energy state to pass therethrough substantially uninhibited, and to substantially inhibit propagation of energy in the first energy state.

3. The energy device of claim 2, wherein the different energy states comprise first and second energy encoding states, and the energy encoding element comprises an energy polarizing element.

4. The energy device of claim 3, wherein the energy encoding element comprises a polarization element selected from a group consisting of:

a) a linear polarizer;

b) a circular polarizer;

c) a quarter, half, or full waveplate; and

d) an energy polarization modulating device.

5. The energy device of claim 3, wherein the first plurality of regions of the energy element each comprise an energy encoding element having a first optical axis, and the second plurality of regions of the energy element each comprise an energy encoding element having a second optical axis.

6. The energy device of claim 3, wherein the energy locations in the first and second regions of are interlaced or woven by energy encoding states.

7. The energy device of claim 3, wherein the energy locations in the first and second regions of are grouped and interlaced or woven by energy encoding states.

8. The energy device of claim 2, wherein the plurality of first regions and the plurality of second regions of the energy encoding element cooperate to define an aperture for each waveguide element.

9. The energy device of claim 2, wherein the plurality of first regions and the plurality of second regions of the energy encoding element cooperate to define a plurality of apertures for each waveguide element.

10. The energy device of claim 2, further comprising an energy combining element configured to relay energy between a plurality of energy devices and an energy location surface formed on the energy combining element, wherein the plurality of energy locations are located on the energy location surface of the energy combining element, and further wherein energy propagating through different energy devices are relayed through interlaced or woven energy locations on the energy location surface.

11. The energy device of claim 10, wherein the energy combining element comprises an element exhibiting transverse Anderson localization.

12. The energy device of claim 10, wherein energy encoding states are retained through the energy combining element and the interlaced energy locations retain alternating encoded energy states.

13. The energy device of claim 12, wherein the alternating energy states are orthogonal polarization states.

14. The energy device of claim 1, wherein the energy encoding element is located on the second side of the array of waveguide elements.

15. The energy device of claim 1, wherein the energy encoding element is located on the first side between the plurality of energy locations and the array of waveguide elements.

16. A energy device comprising:

an array of waveguide elements, wherein the array of waveguide elements comprises a first side and a second side, the array of waveguide elements being configured to direct energy therethrough along a plurality of energy propagation paths which extend through a plurality of energy locations on the first side of the array; and

an energy encoding element operable to limit propagation of energy along the plurality of energy propagation paths;

wherein uninhibited energy propagation paths through first and second waveguide elements of the array of waveguide elements define first and second regions of energy locations, the first and second regions being overlapping and offsetting; and further wherein, at a first moment in time, the energy encoding element substantially inhibits energy propagation paths through energy locations in the first region, and the energy encoding element allows substantially uninhibited energy propagation paths through energy locations in the second region;

wherein at a second moment in time, the energy encoding element substantially inhibits energy propagation paths through energy locations in the second region, and the energy encoding element allows substantially uninhibited energy propagation paths through energy locations in the first region.

wherein temporally aggregated uninhibited energy propagation paths through first and second waveguide elements form at least a portion of a volumetric energy field defined by a 4D plenoptic function.

17. The energy device of claim 16, wherein the energy encoding element comprises an active energy encoding system configured to switch between at least a first state and a second state, wherein, when driven to the first state, the active energy encoding system is configured to form a

first set of apertures, and when driven to the second state, the active energy encoding system is configured to form a second set of apertures.

18. The energy device of claim 17, wherein the first and second sets of apertures are formed by energy encoding elements of the active energy encoding system.

19. The energy device of claim 18, wherein the energy encoding elements comprise active aperture barriers.

20. The energy device of claim 19, wherein the active aperture barriers comprise shutters.

21. The energy device of claim 17, wherein the first and second sets of apertures are formed by controlling one or more energy encoding elements of the active energy encoding system in cooperation with one or more passive energy encoding elements of the active energy encoding system.

22. The energy device of claim 21, wherein the one or more active energy encoding elements are selected from a group consisting of:

a) an energy polarization switch;
b) an energy bandpass switch; and
c) an energy modulation device.

23. The energy device of claim 21, wherein the one or more passive energy encoding elements are selected from a group consisting of:

a) an energy polarization filter;
b) an energy bandpass filter; and
c) an energy waveguide.

24. The energy device of claim 21, wherein the one or more active energy elements encode energy into different energy states and the one or more passive energy elements encode energy based on the energy states.

25. The energy device of claim 24, wherein the one or more active energy elements temporally encode energy at a contiguous group of energy locations into different energy states.

26. The energy device of claim 24, wherein the one or more active energy elements temporally encode energy at interlaced or woven energy locations into different energy states.

27. The energy device of claim 21, wherein the one or more passive energy elements encode energy into different energy states and the one or more active energy encoding elements selectively direct energy based on the energy states.

28. The energy device of claim 27, wherein the one or more passive energy elements encode energy into different energy states at interlaced or woven energy locations.

29. The energy device of claim 17, wherein the first and second sets of apertures are formed such that a plurality of apertures are formed for each waveguide element, and wherein the energy encoding element further comprises a split aperture energy encoding element configured to limit propagation of energy along the plurality of energy propagation paths through the plurality of apertures for each waveguide element.

30. The energy device of claim 17, wherein the first and second sets of apertures are formed such that a plurality of apertures are formed for each waveguide element, and wherein energy is directed through the plurality of apertures for each waveguide element temporally.

31. The energy device of claim 16, the active energy encoding system is configured to switch to one or more additional states, wherein, when driven to one or more additional states, the active energy encoding system is configured to form one or more additional sets of apertures.

32. An energy system, comprising:

an energy device subsystem comprising:

a first energy device having a first plurality of energy locations; and

a second energy device having a second plurality of energy locations; and

an energy combining element configured to relay energy between the energy device subsystem and an energy location surface formed on the energy combining element, wherein the plurality of energy locations are located on the energy location surface of the energy combining element;

wherein the first and second energy devices are superimposed in a relative orientation such that superimposing an arrangement of the first plurality of energy locations and an arrangement of the second plurality of energy locations result in a third plurality of energy locations at energy location surface, the number of third plurality of energy locations being greater than the sum of the first and second plurality combined for each non-boundary region with resultant energy location sizes that are different than either of the first or second energy locations.

33. The energy device of claim 32, wherein the first plurality of energy locations comprise energy locations defined in rectangular regions.

34. The energy device of claim 32, wherein the first and second plurality of energy locations comprise energy locations defined in rectangular regions.

35. The energy device of claim 32, wherein the first plurality of energy locations comprise energy locations defined in square regions.

36. The energy device of claim 32, wherein the first plurality of energy locations comprise energy locations defined in rectangular regions, and wherein the second plurality energy location comprise energy locations defined as any of square, round, rectangle, triangular, hexagonal, delta structure, regular or non-regular regions.

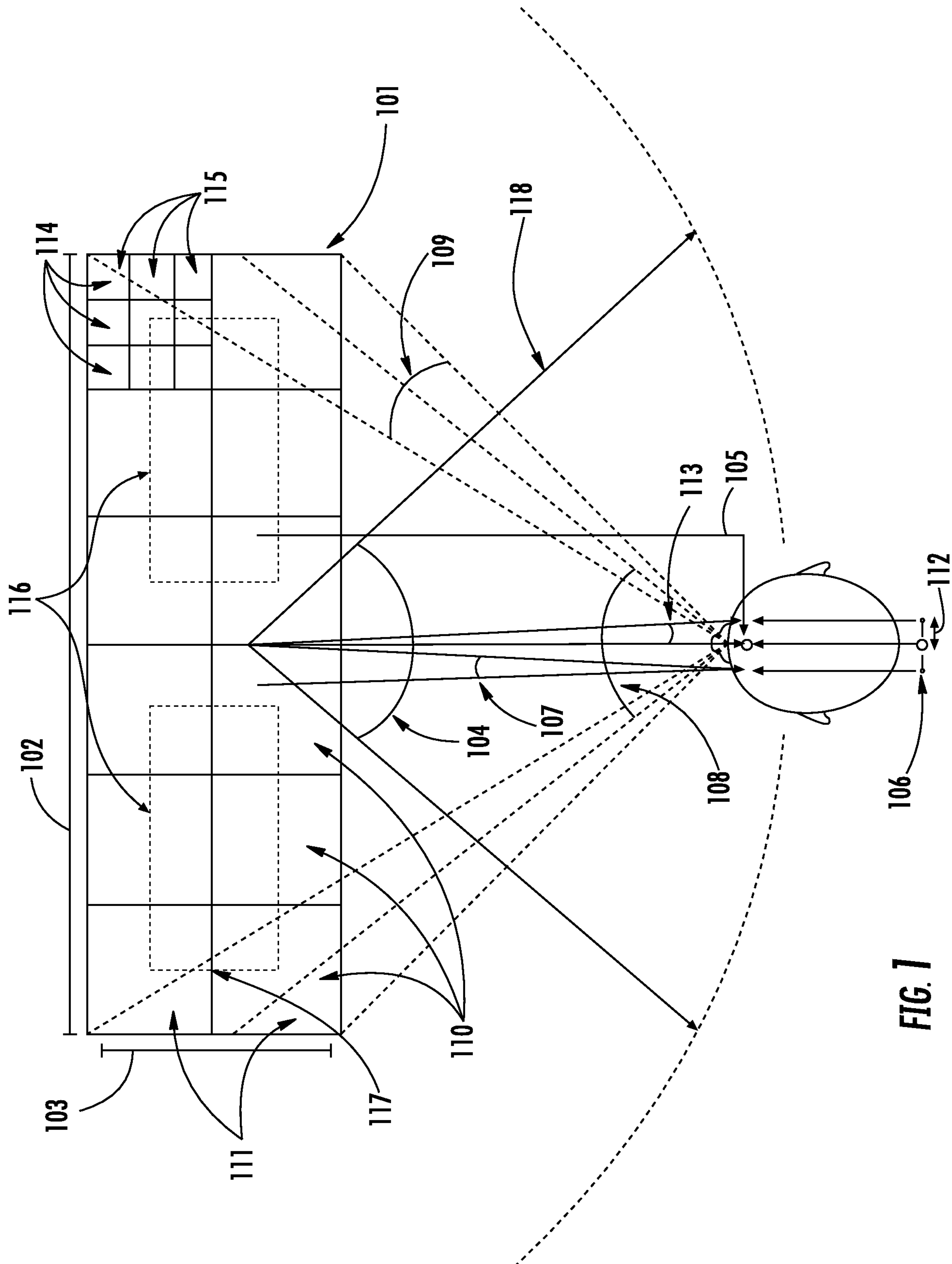
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FIG. 1

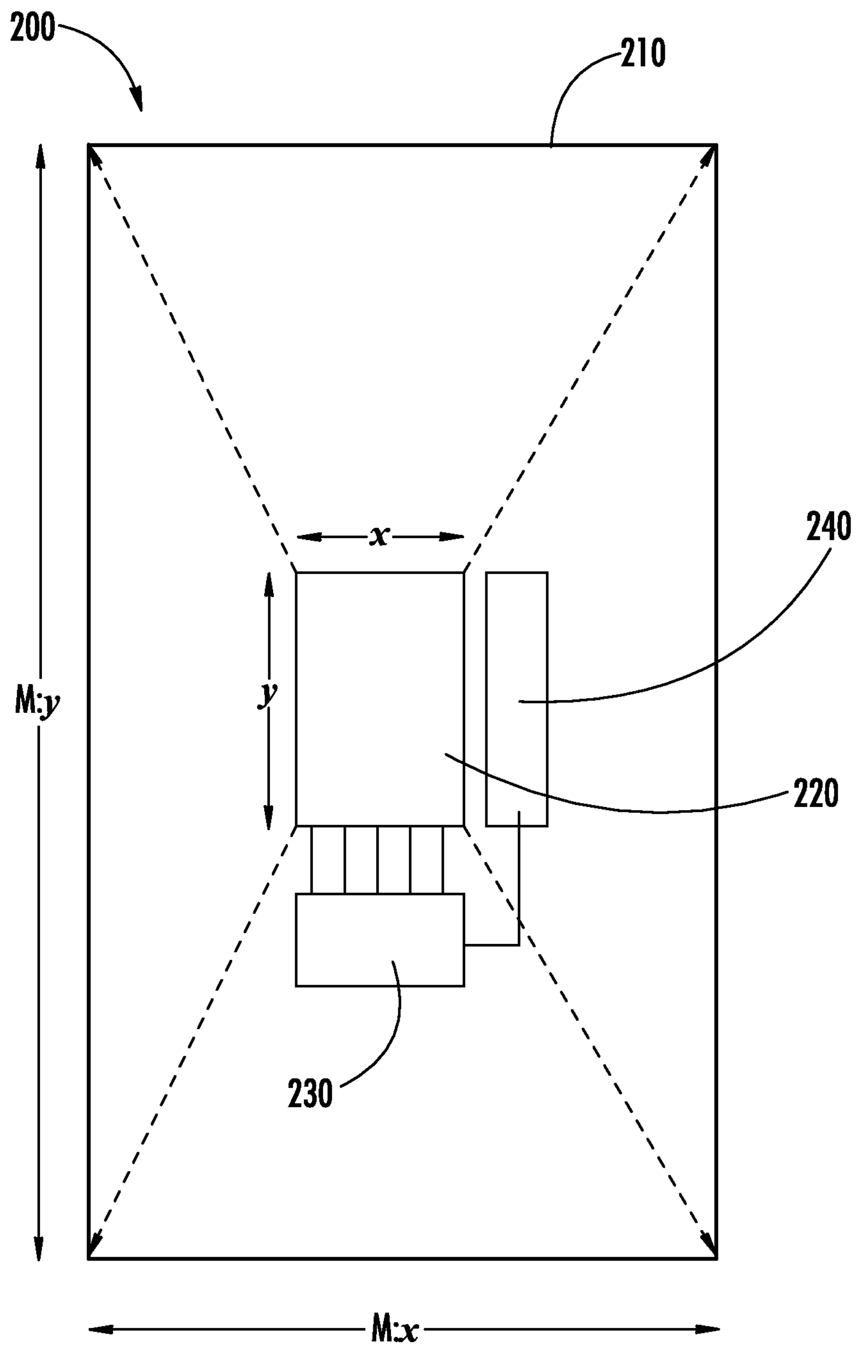

FIG. 2

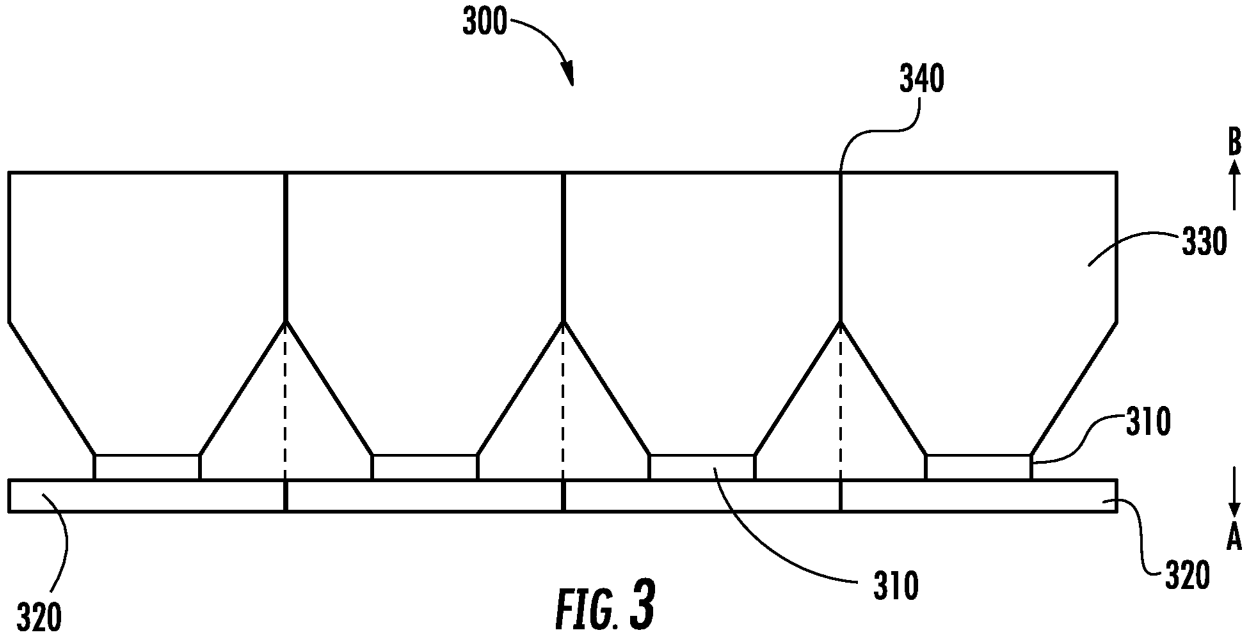

FIG. 3

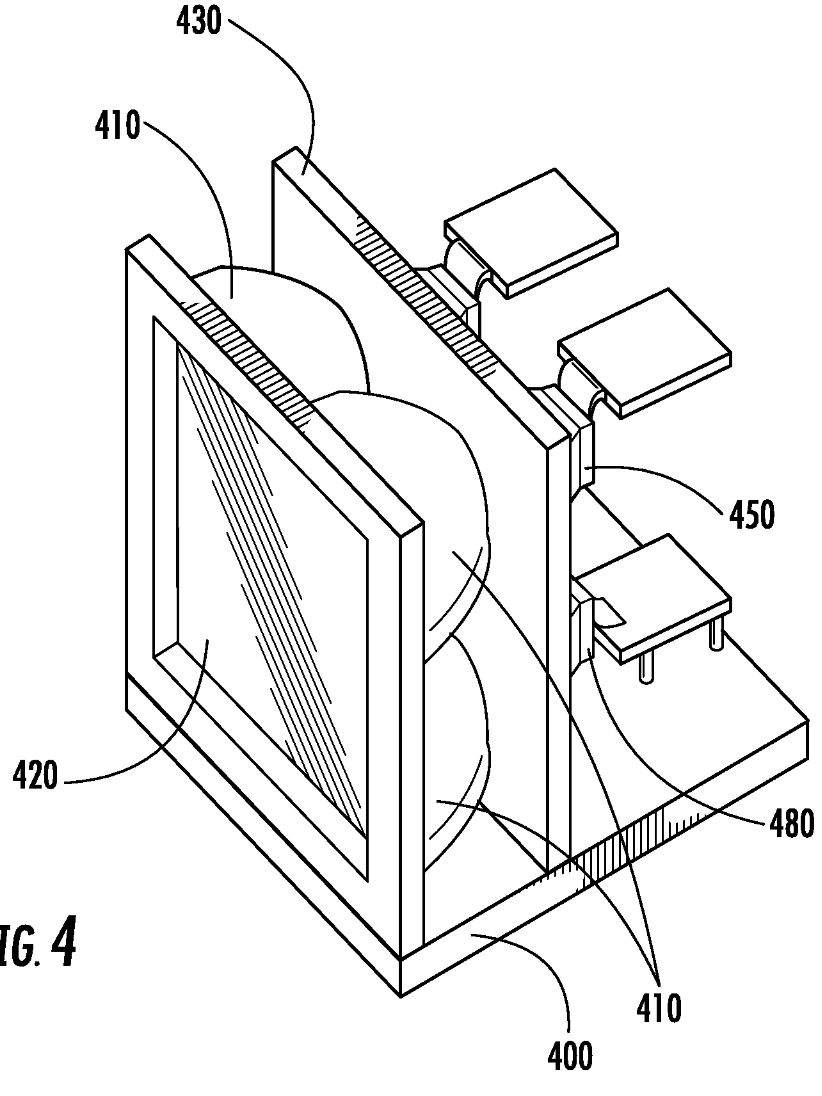

FIG. 4

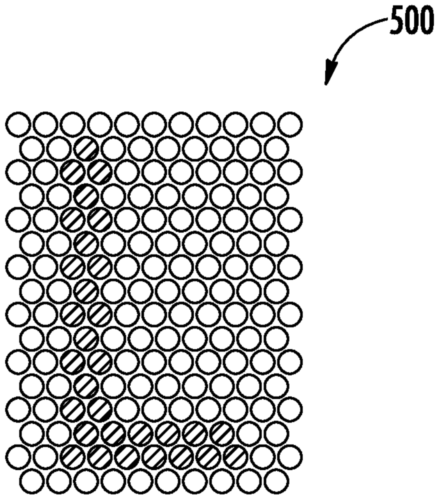

FIG. 5A

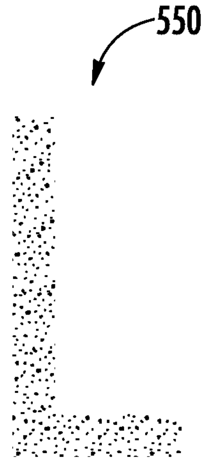

FIG. 5B

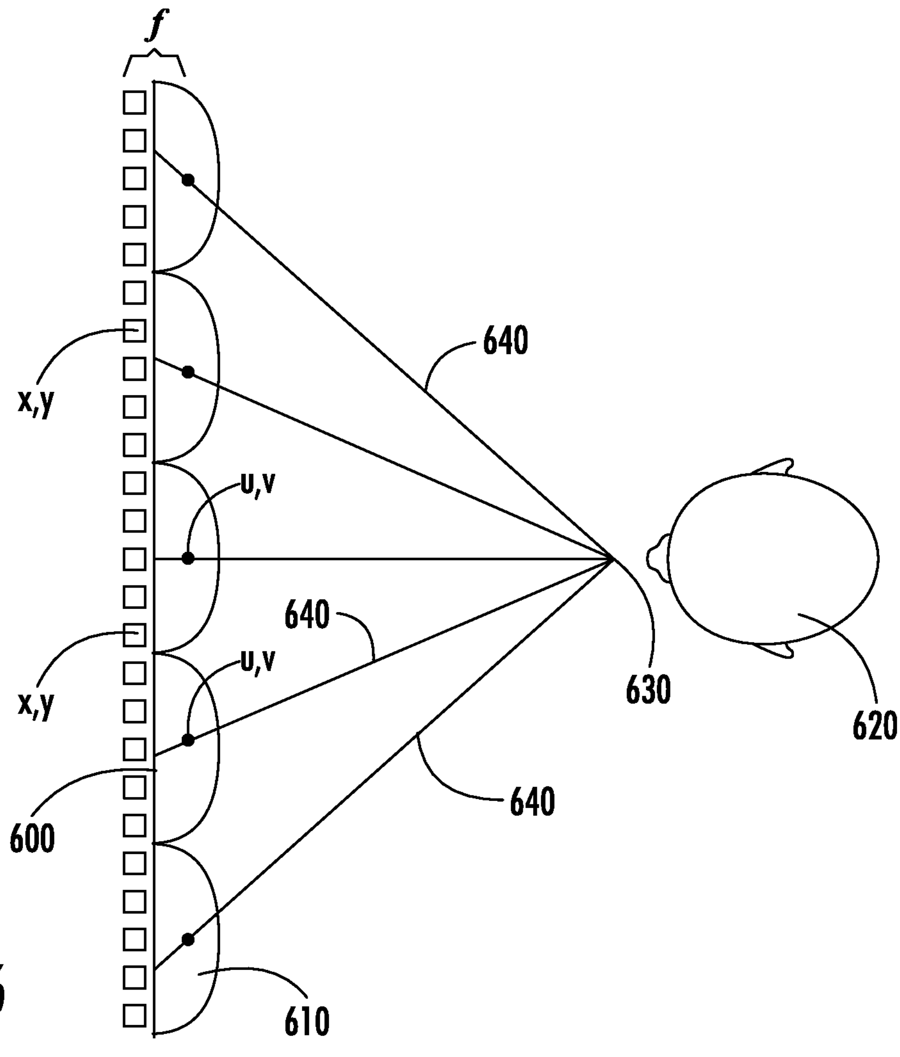

FIG. 6

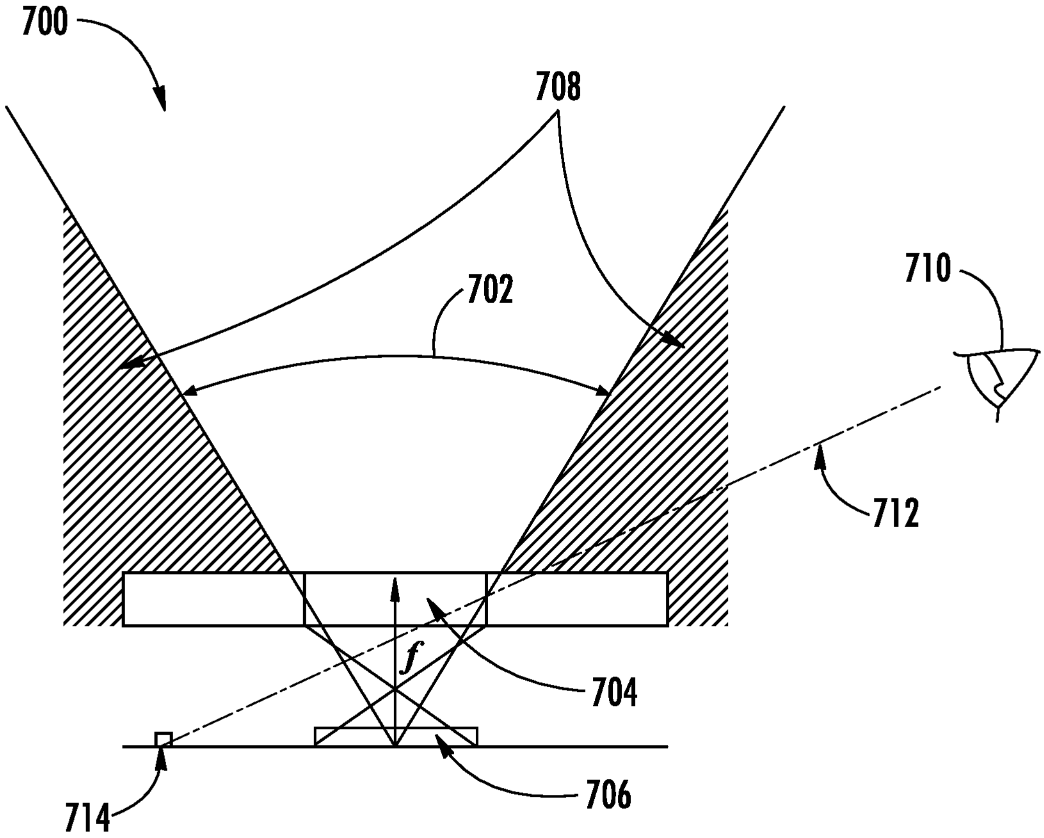

FIG. 7

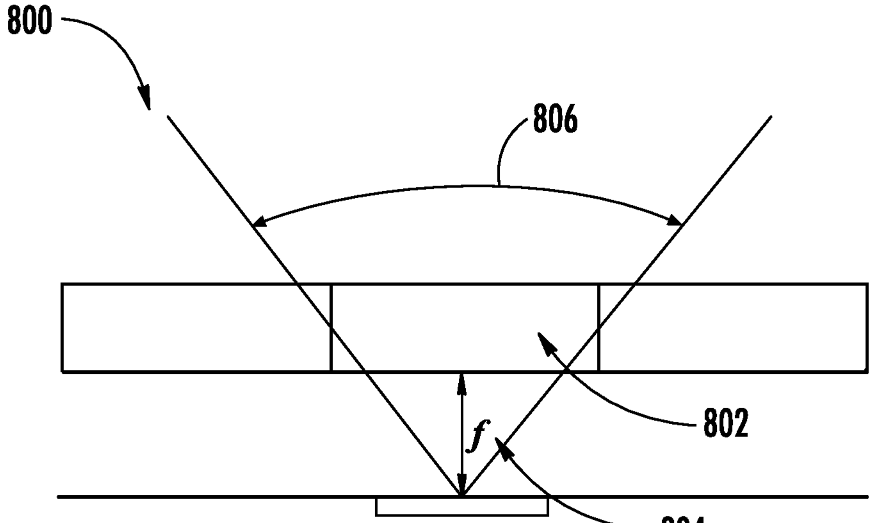

FIG. 8

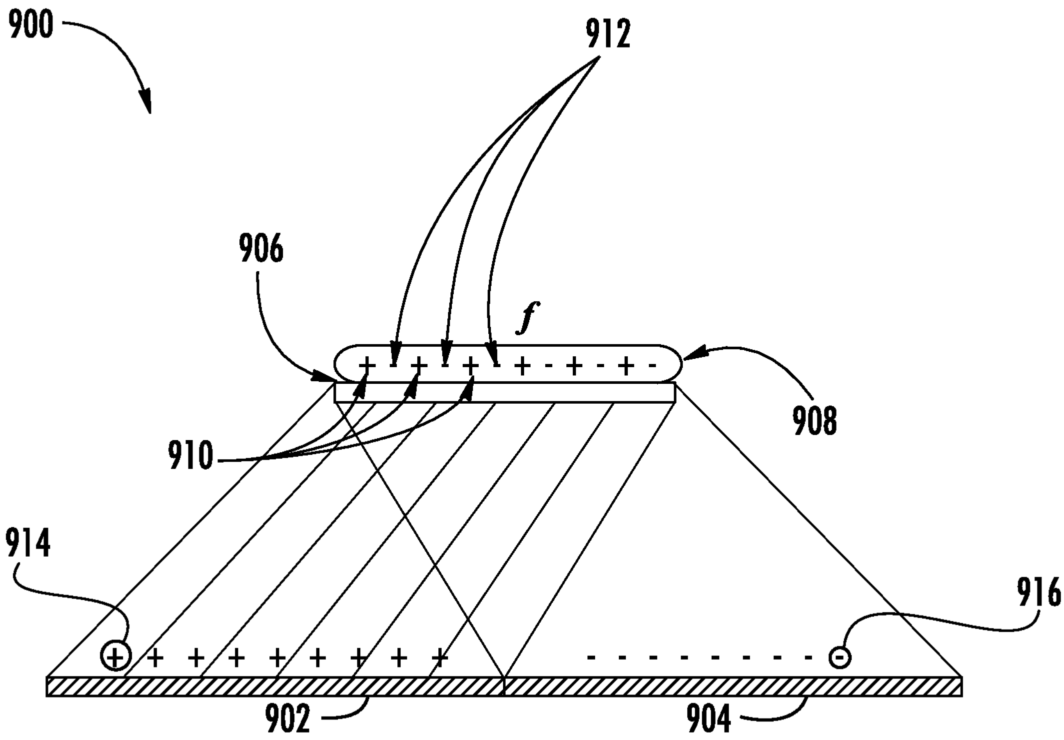

FIG. 9

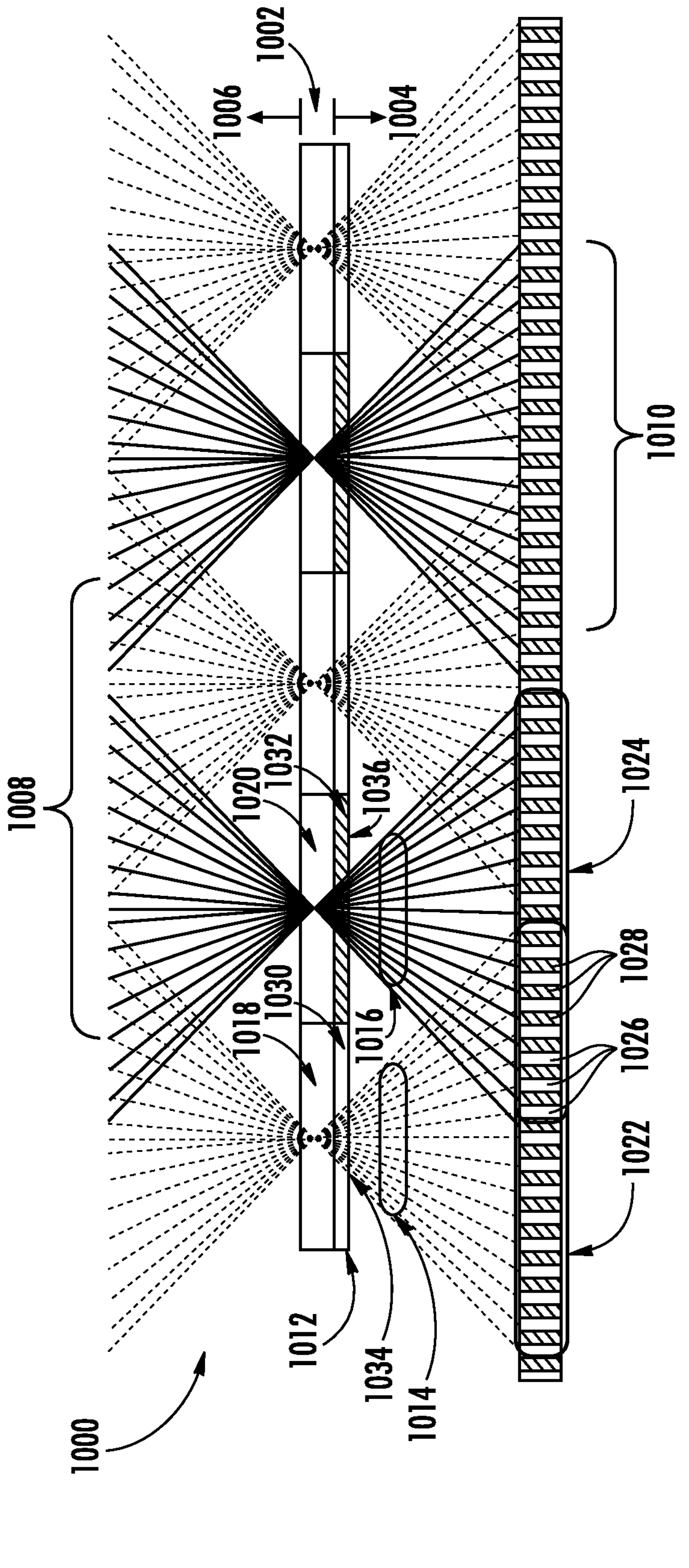
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FIG. 10

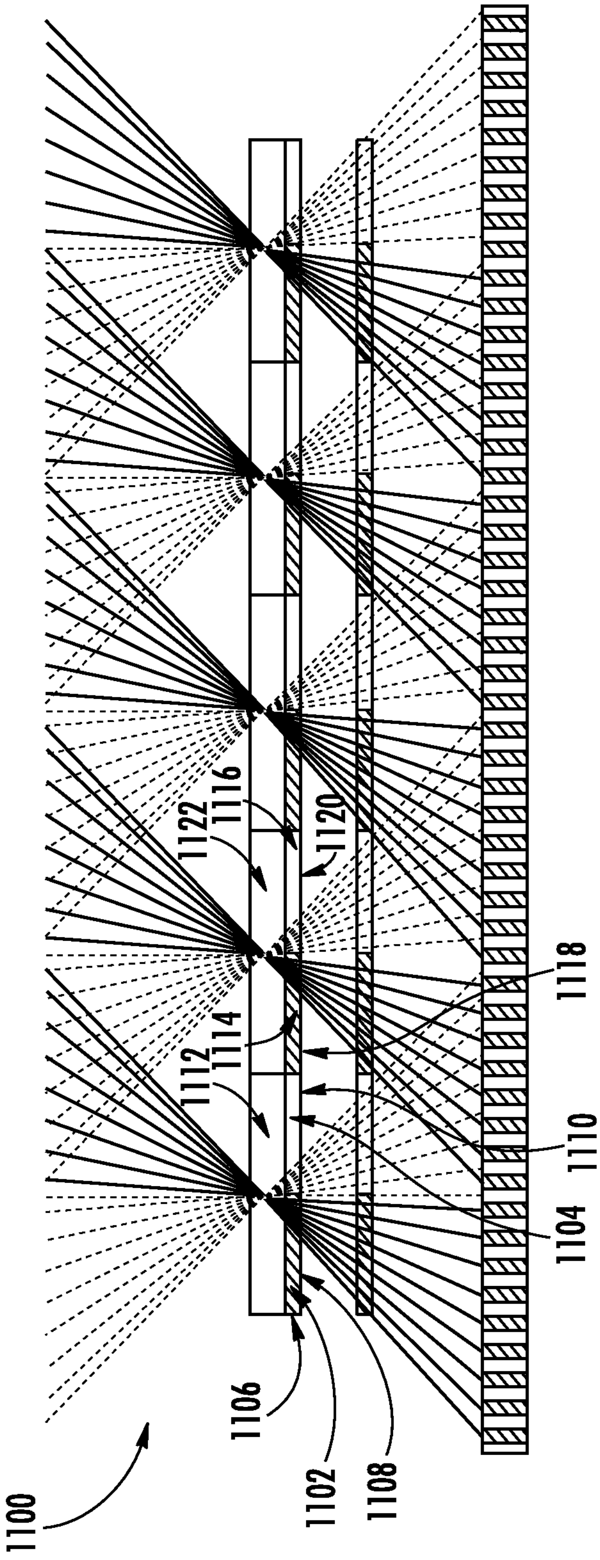

FIG. 11

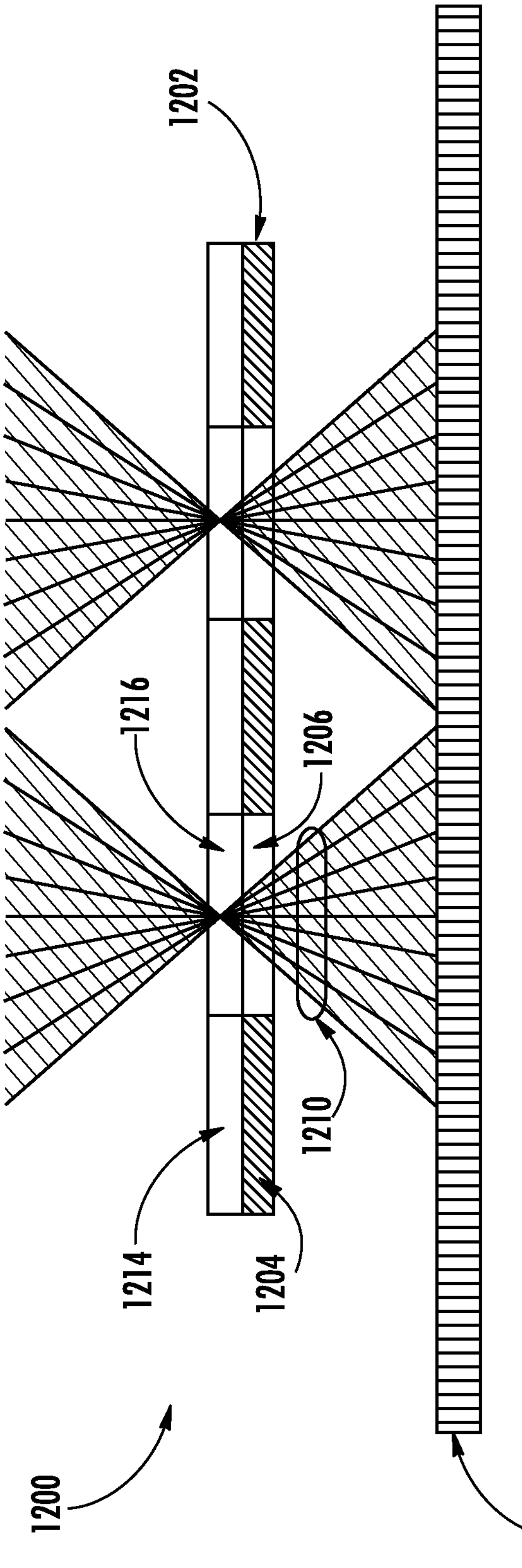

FIG. 12A

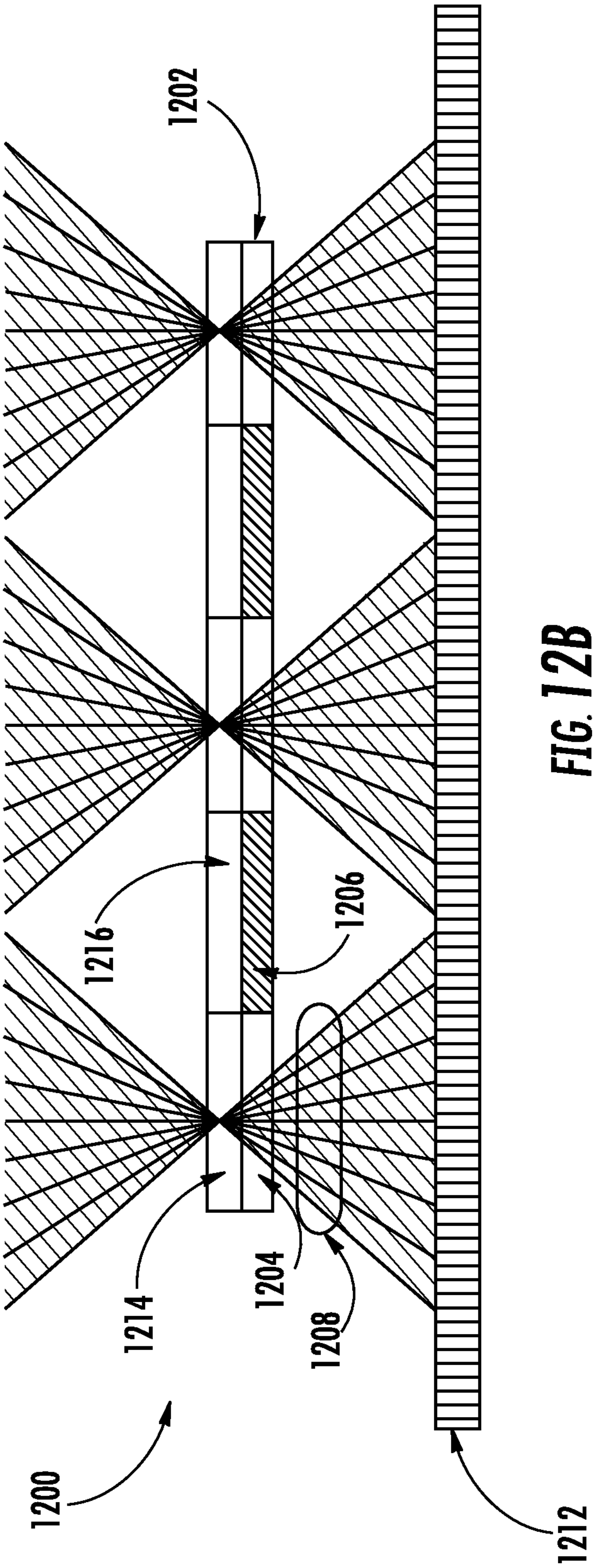

FIG. 12B

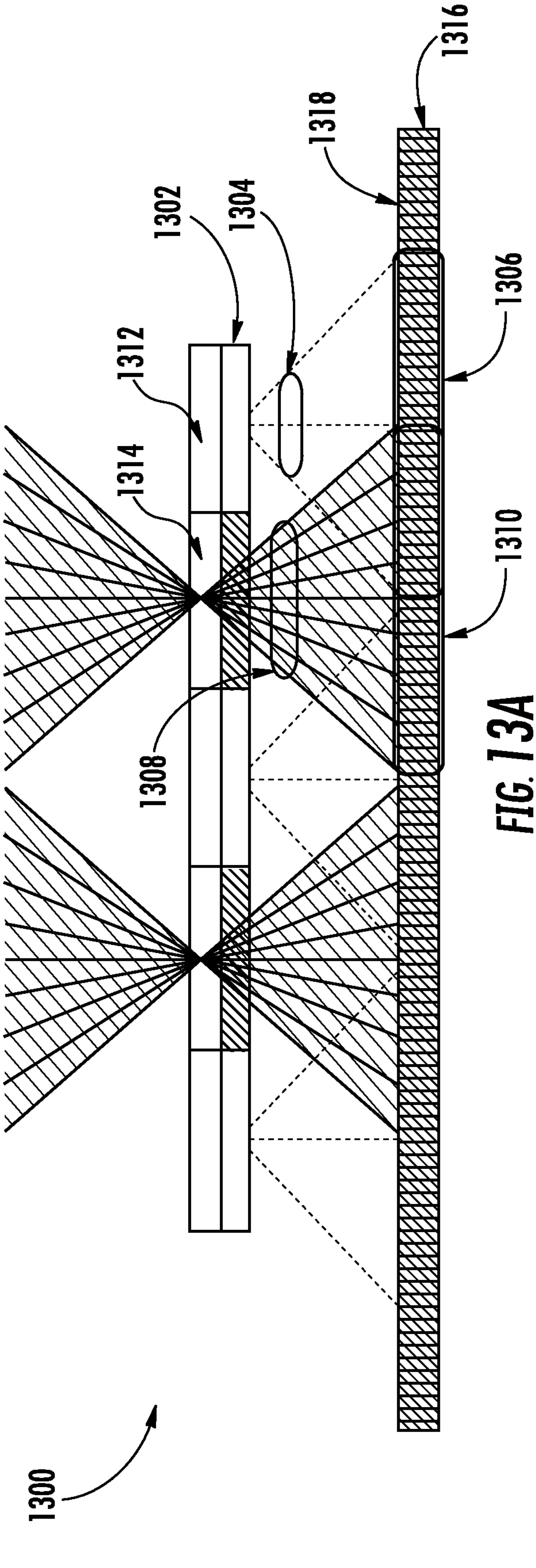

FIG. 13A

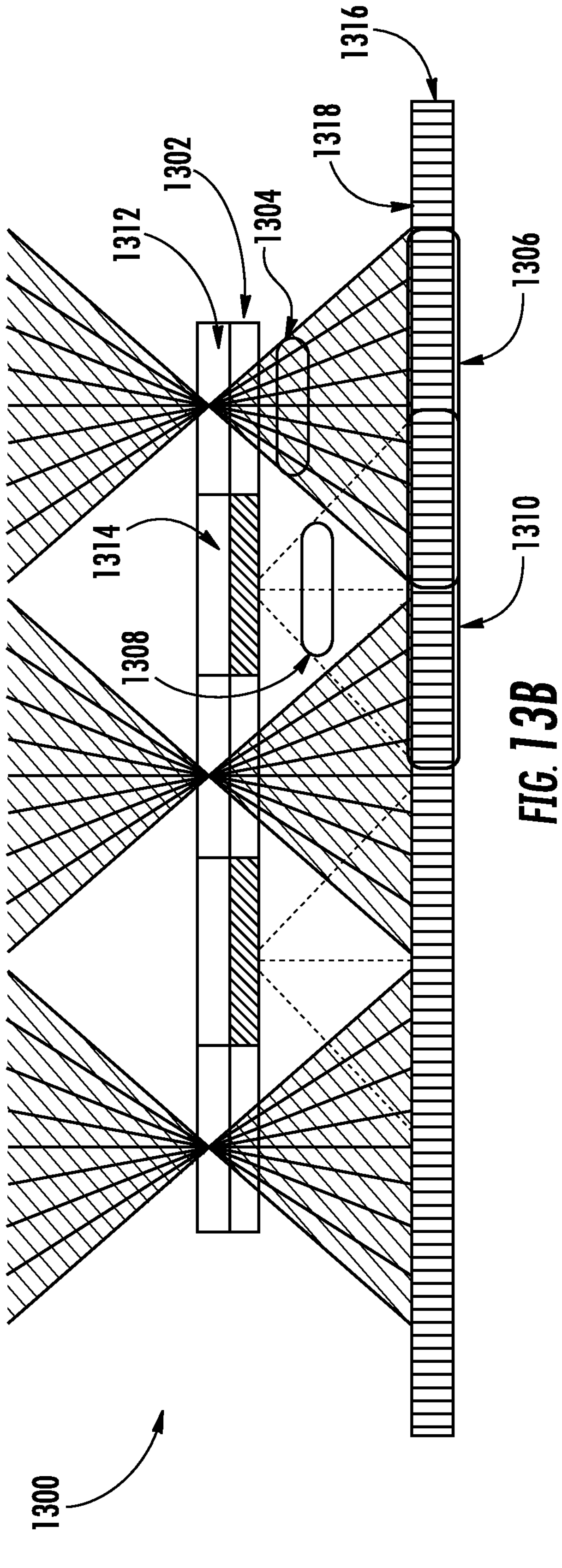

FIG. 13B

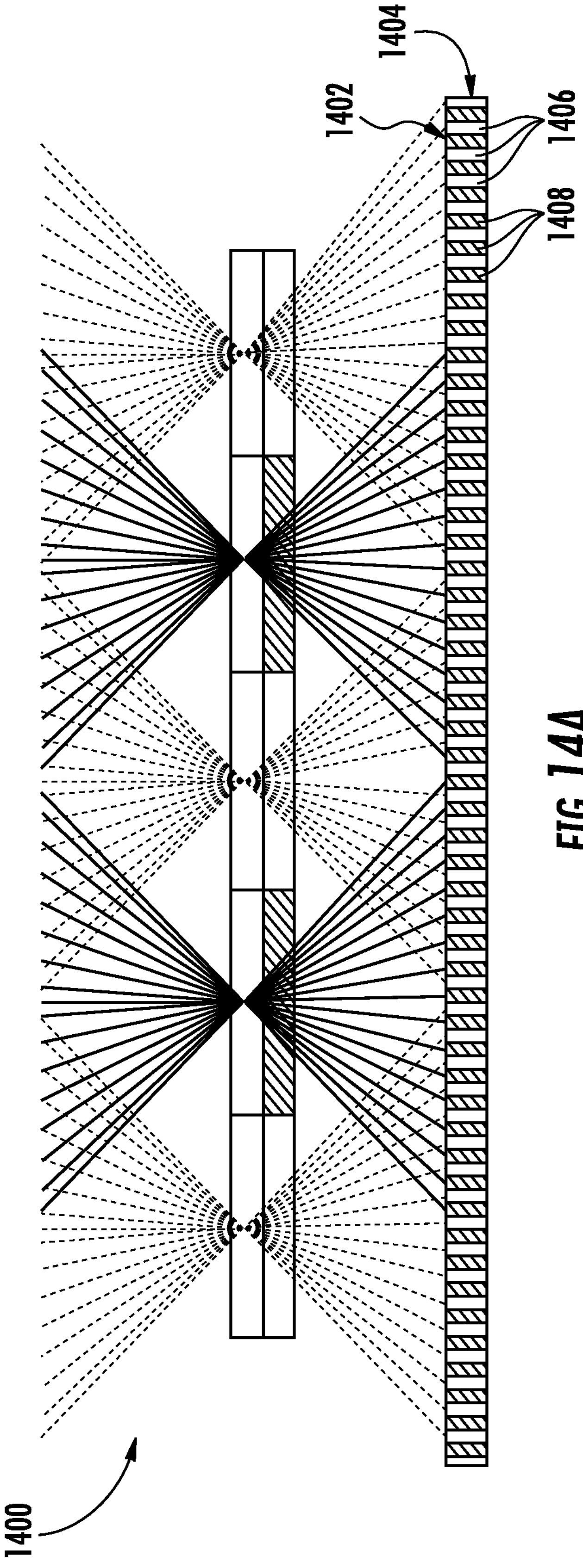

FIG. 14A

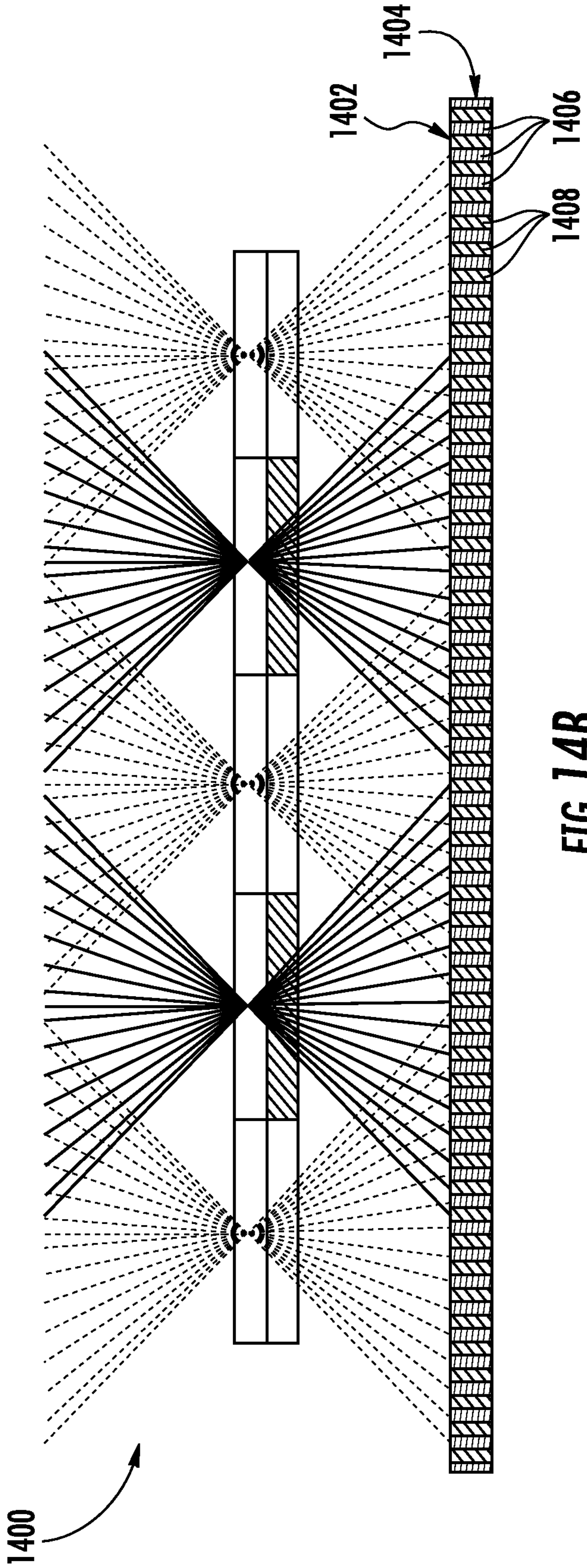

FIG. 14B

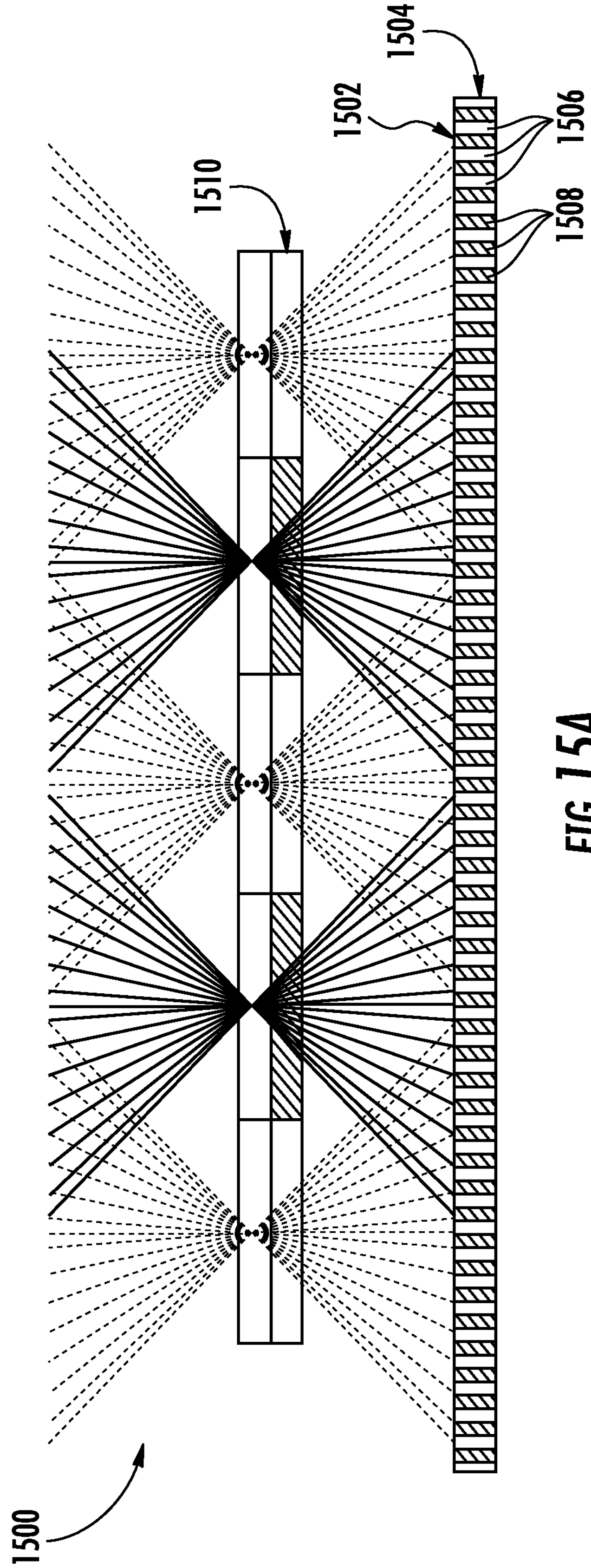

FIG. 15A

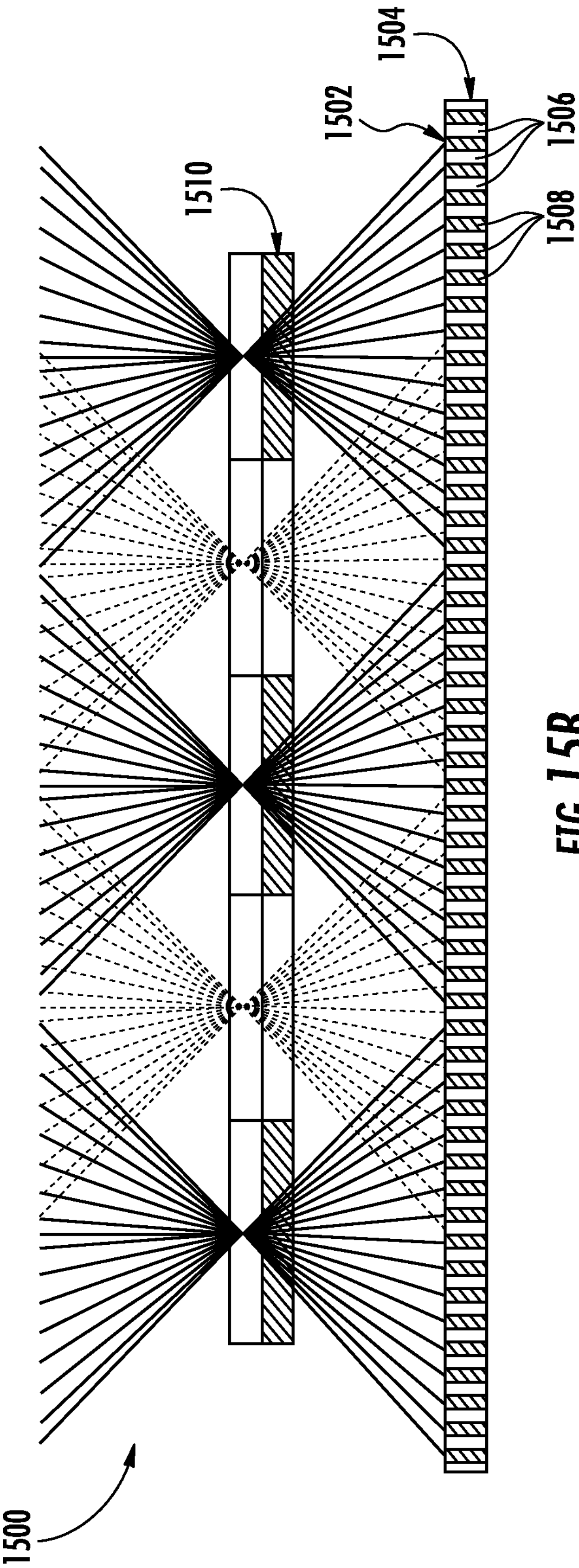

FIG. 15B

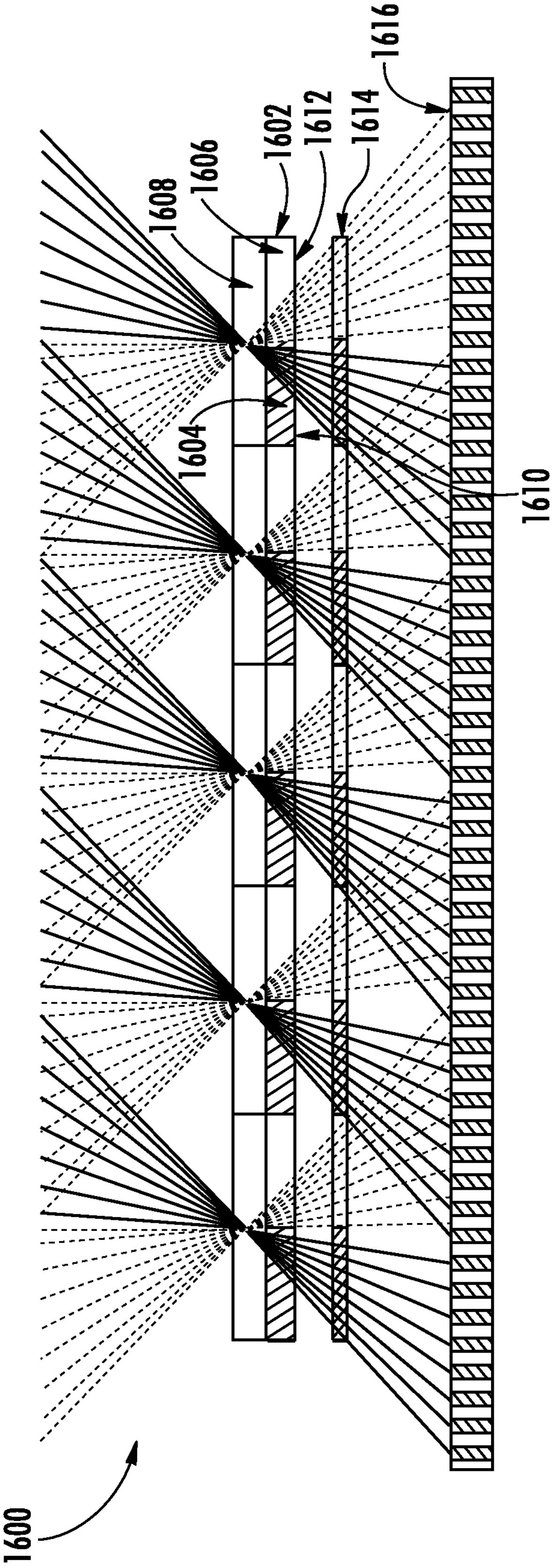

FIG. 16A

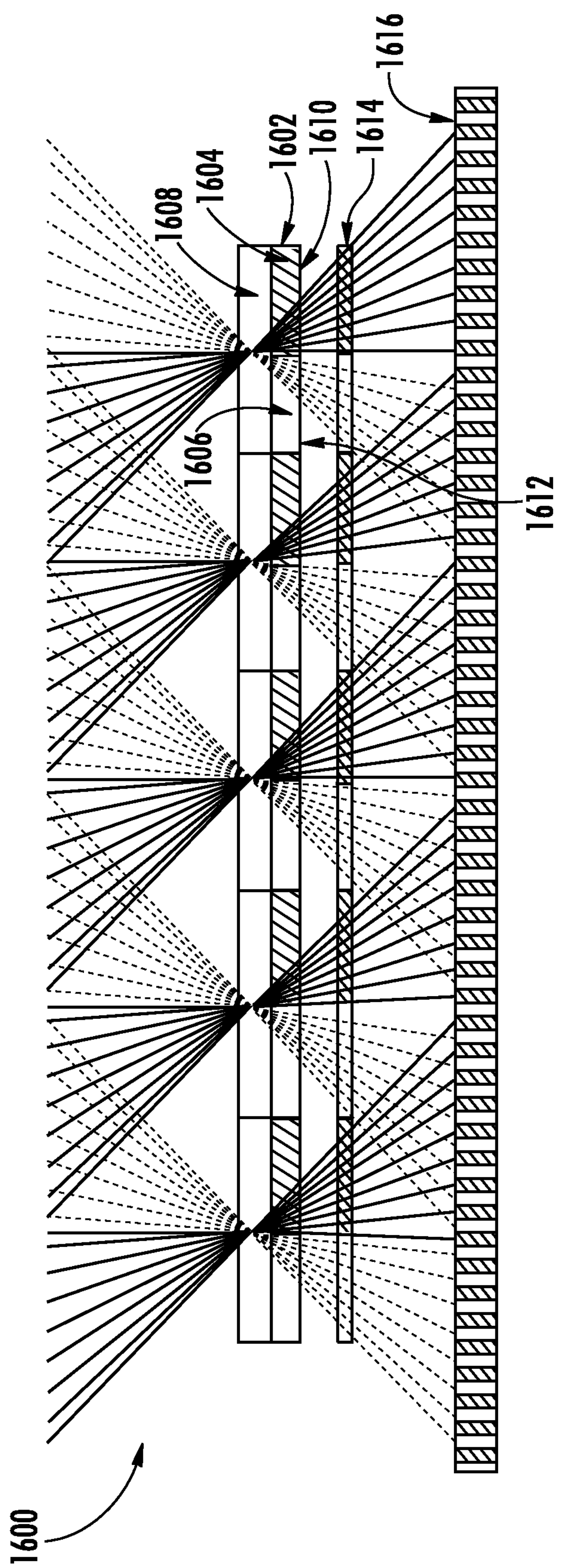

FIG. 16B

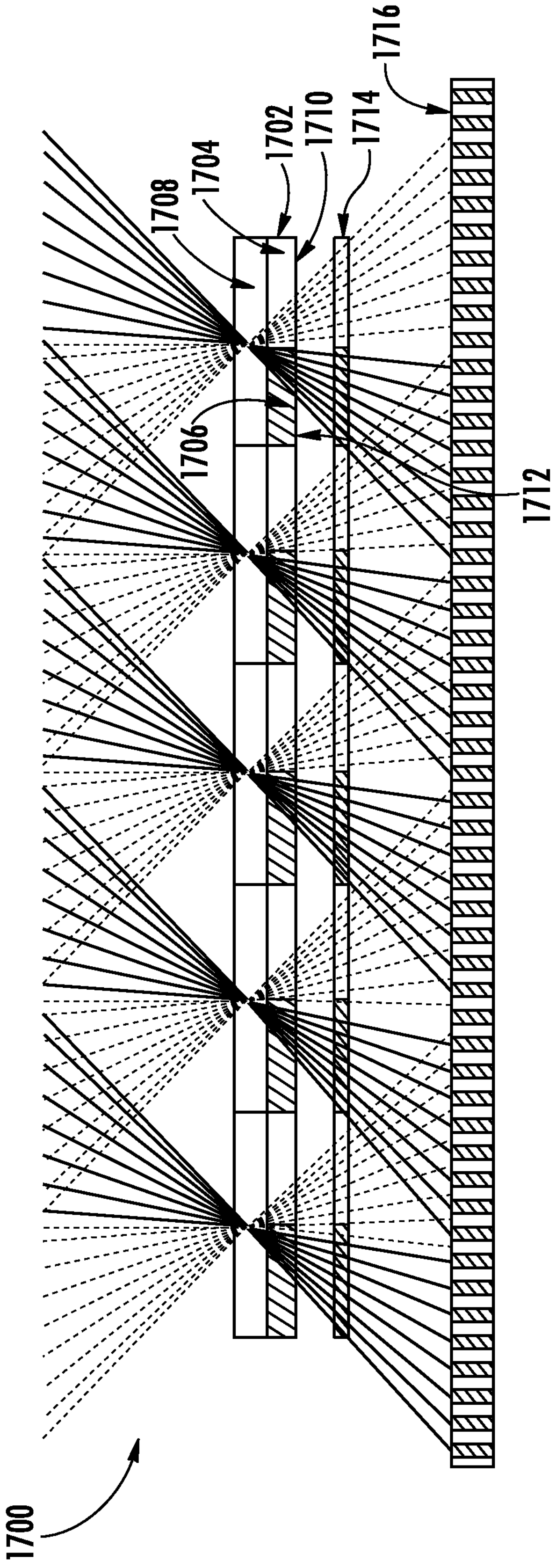

FIG. 17A

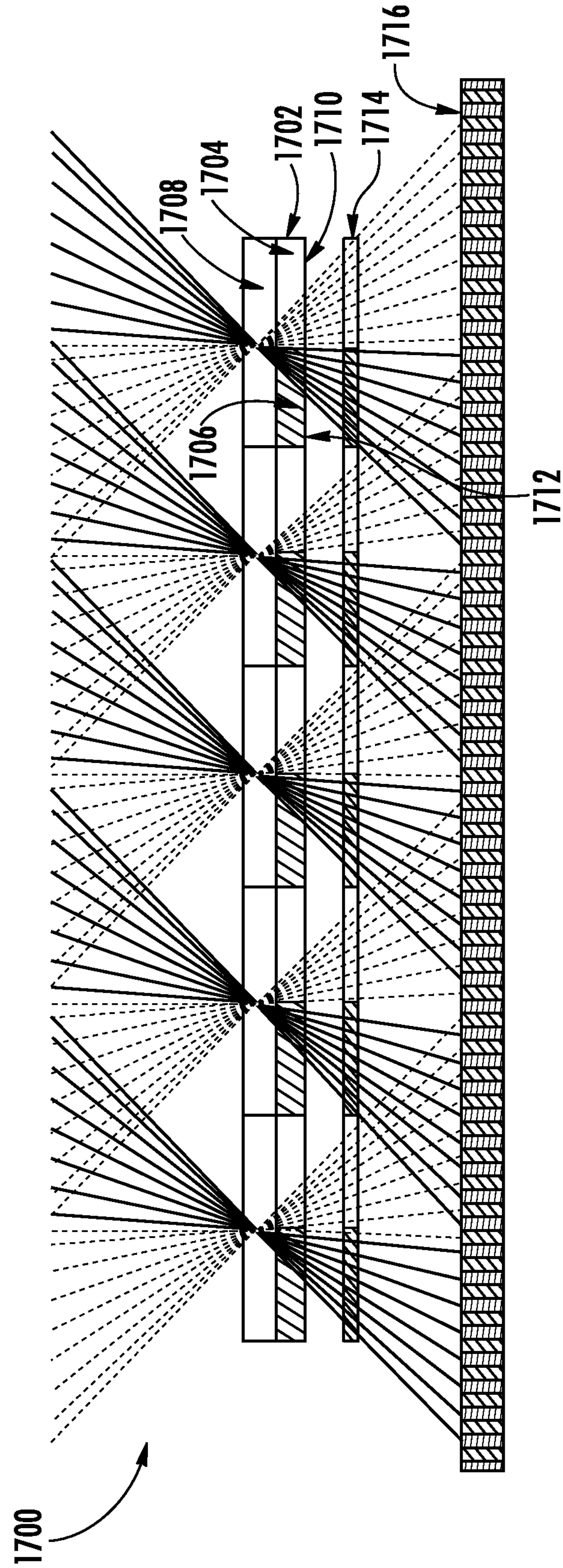

FIG. 17B

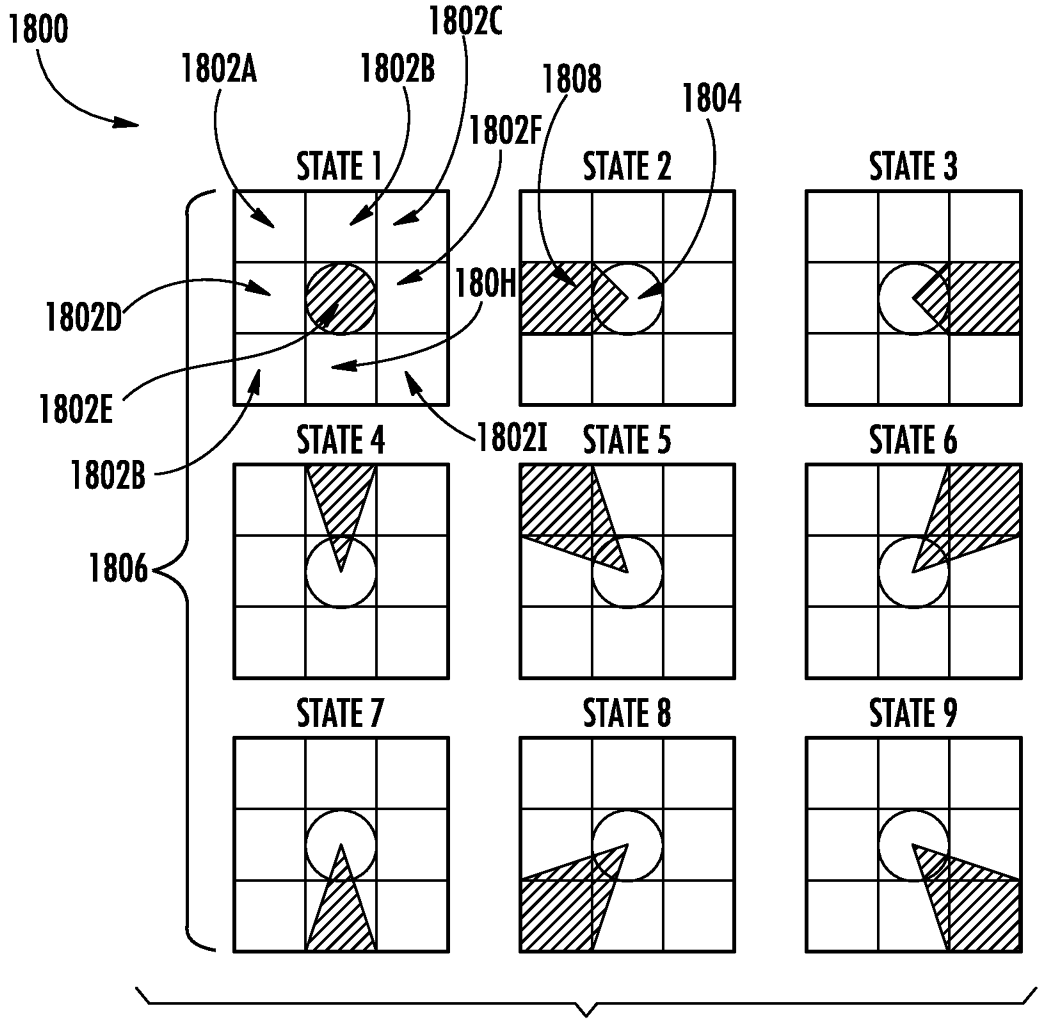
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FIG. 18

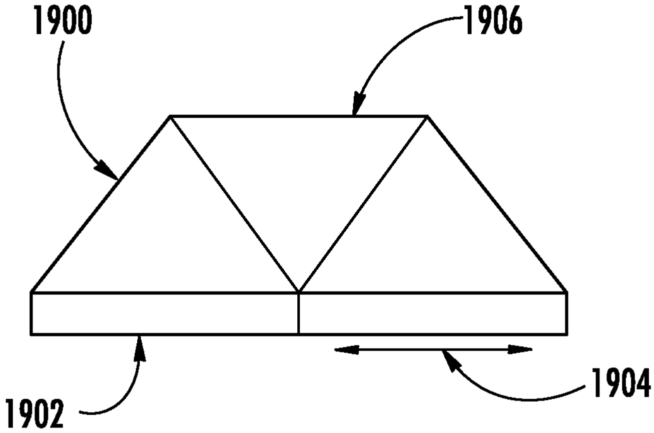

FIG. 19A

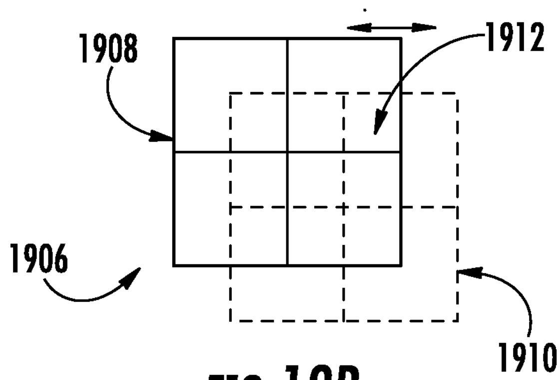

FIG. 19B

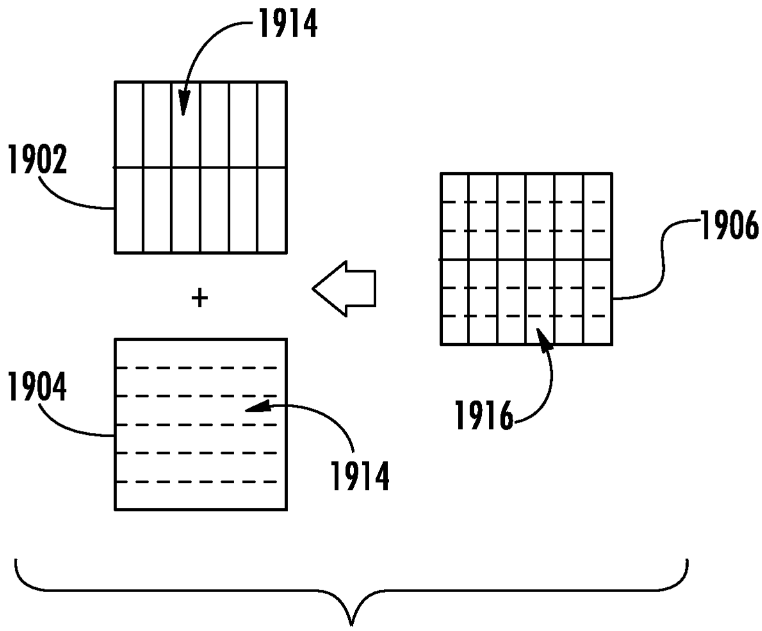

FIG. 19C

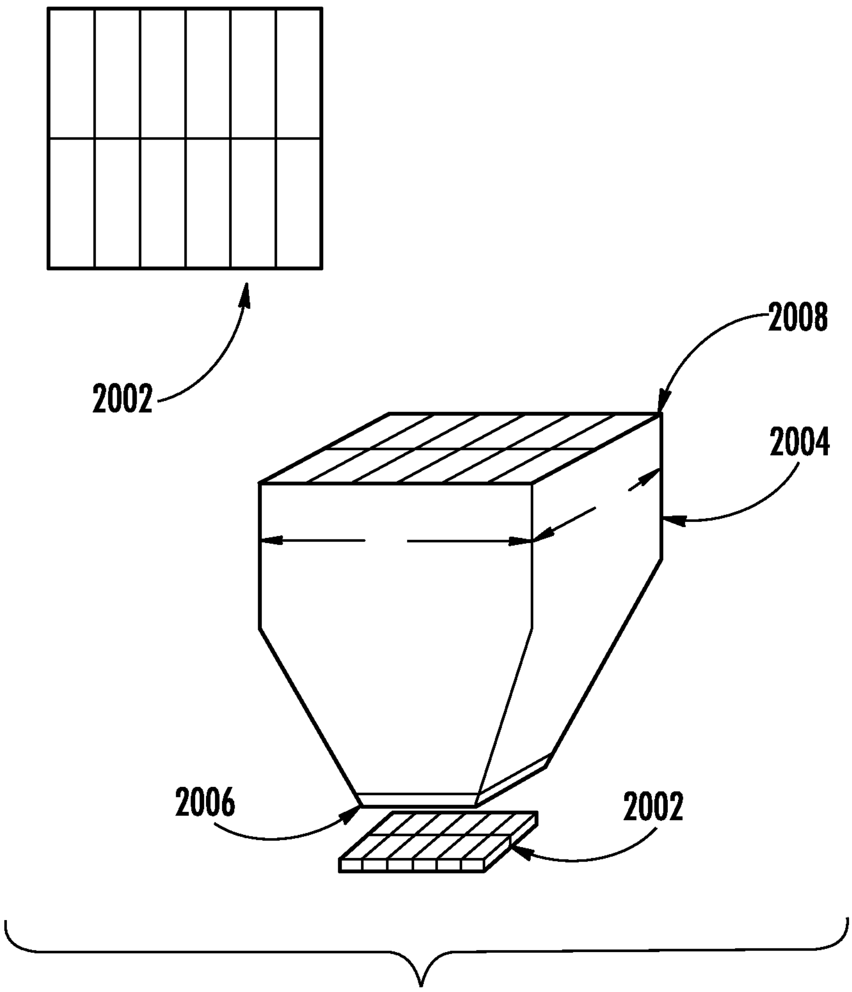

FIG. 20

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US 17/42468

A. CLASSIFICATION OF SUBJECT MATTER
IPC(8) - H01P 3/12 (2017.01)
CPC - H01P 3/16; H01P 3/12; H01P 5/00; H01P 11/0; G01N 21/648

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
See Search History Document

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
See Search History Document

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
See Search History Document

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2012/0206726 A1 (Pervez et al.) 16 August 2012 (16.08.2012), entire document, especially para. [0035], [0046], [0090]	1-31
A	WO 2014/188149 A1 (MILAN POPOVICH et al.) 27 November 2014 (27.11.2014), entire document, especially p. 17, ln. 22 to p. 19, ln. 2; p. 23, ln. 9-19	1-31
A	US 2016/0205394 A1 (LINGFEI MENG et al.) 14 July 2016 (14.07.2016) entire document, especially para. [0031], [0041], [0051], [0055]	1-31
A	US 2010/0278480 A1 (Vasylyev) 04 November 2010 (04.11.2010), entire document	1-31
A	WO 2016/046514 A1 (KIMBERLY SUN LOKOVIC et al.) 31 March 2016 (31.03.2016), entire document	1-31

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
08 November 2017	27 NOV 2017

Name and mailing address of the ISA/US	Authorized officer:
Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-8300	Lee W. Young PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US 17/42468

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:
Group I: claims 1-31: drawn to an energy device.

Group II: claim 32-36: drawn to an energy system.

---see extra sheet---

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:
1-31

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☐ No protest accompanied the payment of additional search fees.

Box No. III: Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This application contains the following inventions or groups of inventions which are not so linked as to form a single general inventive concept under PCT Rule 13.1. In order for all inventions to be examined, the appropriate additional examination fees must be paid.

Group I: claims 1-31: drawn to an energy device.

Group II: claim 32-36: drawn to an energy system.

The inventions listed as Groups I and II do not relate to a single general inventive concept under PCT Rule 13.1 because, under PCT Rule 13.2, they lack the same or corresponding special technical features for the following reasons:

Special technical features:
Group I requires an array of waveguide elements, wherein the array of waveguide elements comprises a first side and a second side, the array of waveguide elements being configured to direct energy therethrough along a plurality of energy propagation paths which extend through a plurality of energy locations on the first side of the array; and an energy encoding element operable to limit propagation of energy along the plurality of energy propagation paths; wherein uninhibited energy propagation paths through first and second waveguide elements of the array of waveguide elements define first and second regions of energy locations, the first and second regions being overlapping and offsetting; and further wherein, the energy encoding element substantially limits propagation of energy through each energy location in the first and second regions to one uninhibited energy propagation path; wherein the uninhibited energy propagation paths through first and second waveguide elements form at least a portion of a volumetric energy field defined by a 4D plenoptic function, not found in the other groups.

Group II requires an energy device subsystem comprising: a first energy device having a first plurality of energy locations; and a second energy device having a second plurality of energy locations; and an energy combining element configured to relay energy between the energy device subsystem and an energy location surface formed on the energy combining element, wherein the plurality of energy locations are located on the energy location surface of the energy combining element; wherein the first and second energy devices are superimposed in a relative orientation such that superimposing an arrangement of the first plurality of energy locations and an arrangement of the second plurality of energy locations result in a third plurality of energy locations at energy location surface, the number of third plurality of energy locations being greater than the sum of the first and second plurality combined for each non-boundary region with resultant energy location sizes that are different than either of the first or second energy locations, not found in the other groups.

Shared Features:
The only technical features shared by Groups I and II that would otherwise unify the groups are an energy device with an energy combining element.

However, these shared technical features do not represent a contribution over prior art, because the shared technical features are disclosed by US 5,199,090 A to Bell 30 March 1993 (30.03.1993), which discloses an energy device with an energy combining element (col 10, ln 48 to col 11, ln 18 -The outgoing light in the waveguide branches 73a2, 73b2 is combined at the single mode combining junction 73h of the waveguide 73. Since the outgoing TE light modes of the waveguide branches are in phase with one another, they sum to excite the lowest order outgoing TE light mode in the common or combined waveguide section 73i. This lowest order mode propagates on through the waveguide section 73i toward the recording media 76.).

As the shared technical features were known in the art at the time of the invention, they cannot be considered special technical features that would otherwise unify the groups.

Groups I and II therefore lack unity under PCT Rule 13 because they do not share a same or corresponding special technical feature.