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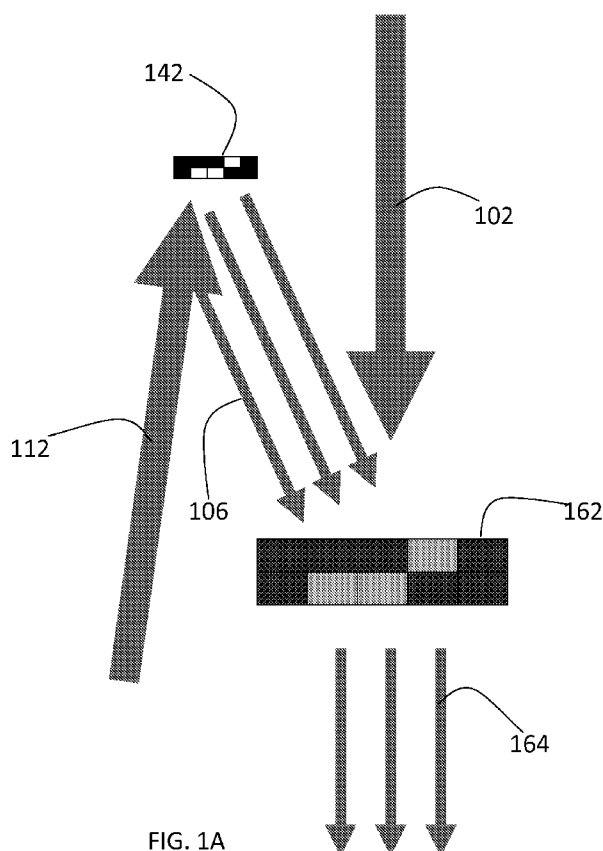
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[Continued on next page]

(54) Title: OPTICALLY DRIVEN TERAHERTZ MODULATOR



(57) Abstract: A system and method for high-resolution imaging terahertz radiation utilizing a spatial terahertz modulator based on interactions of photons at other energies with an intermediate screen to create very high speed modulation.



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**OPTICALLY DRIVEN TERAHERTZ MODULATOR**

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**CROSS-REFERENCE TO RELATED APPLICATIONS**

[0001] The present application claims the benefit of the filing date of U.S. Provisional Patent Application Serial No. 61/306,827 entitled "Optically Driven Terahertz Modulator" and filed by the present inventor on February 22, 2010.

10 [0002] The aforementioned provisional patent application is hereby incorporated by reference in its entirety.

**STATEMENT REGARDING FEDERALLY  
SPONSORED RESEARCH OR DEVELOPMENT**

15 [0003] None.

**BACKGROUND OF THE INVENTION**

## Field Of The Invention

[0004] The invention relates to systems and methods for high resolution imaging terahertz radiation.

20

## Brief Description Of The Related Art

[0005] The large amount of raw data acquired in a conventional digital image or video often necessitates immediate compression in order to store or transmit that data. This compression typically exploits a priori knowledge, such as the fact that an N-pixel image  
25 can be well approximated as a sparse linear combination of  $K \ll N$  wavelets. These appropriate wavelet coefficients can be efficiently computed from the N pixel values and then easily stored or transmitted along with their locations. Similar procedures are

applied to videos containing  $F$  frames of  $P$  pixels each; where  $N=FP$  denotes the number of video “voxels”.

[0006] This process has two major shortcomings. First, acquiring large amounts of raw image or video data (large  $N$ ) can be expensive, particularly at wavelengths where CMOS or CCD sensing technology is limited. Second, compressing raw data can be computationally demanding, particularly in the case of video. While there may appear to be no way around this procedure of “sample, process, keep the important information, and throw away the rest,” a new theory known as Compressive Sensing (CS) has emerged that allows for directly acquiring a compressed digital representation of a signal without first sampling that signal. See Candès, E., Romberg, J., Tao, T., “Robust uncertainty principles: Exact signal reconstruction from highly incomplete frequency information,” IEEE Trans. Inform. Theory 52 (2006) 489–509; David Donoho, “Compressed sensing,” IEEE Transactions on Information Theory, Volume 52, Issue 4, April 2006, Pages: 1289 - 1306; and Candès, E., Tao, T., “Near optimal signal recovery from random projections and universal encoding strategies,” (2004) Preprint.

[0007] Efforts on compressed imaging include Pitsianis, N.P., Brady, D.J., Sun, X.: “Sensor-layer image compression based on the quantized cosine transform,” SPIE Visual Information Processing XIV (2005) and Brady, D.J., Feldman, M., Pitsianis, N., Guo, J.P., Portnoy, A., Fiddy, M., “Compressive optical MONTAGE photography,” SPIE Photonic Devices and Algorithms for Computing VII (2005), which employ optical elements to perform transform coding of multispectral images. Two notable previous DMD-driven applications involve confocal microscopy (Lane, P.M., Elliott, R.P., MacAulay, C.E., “Confocal microendoscopy with chromatic sectioning,” Proc. SPIE.

Volume 4959 (2003) 23–26) and micro-optoelectromechanical (MOEM) systems (DeVerse, R.A., Coifman, R.R., Coppi, A.C., Fateley, W.G., Geshwind, F., Hammaker, R.M., Valenti, S., Warner, F.J., “Application of spatial light modulators for new modalities in spectrometry and imaging,” Proc. SPIE. Volume 4959 (2003)). The beauty  
5 of compressive sensing is that either Gaussian or Bernoulli white-noise patterns serve as appropriate basis functions allowing them to be disassembled into sets of two or more transmissive or reflective modulators where even intermediary combinations would still serve as mathematically acceptable patterns for encoding the image signal.

[0008] While mechanical and electronic terahertz modulators exist, they both suffer from  
10 drawbacks in implementation for high resolution via compressive imaging techniques. In the case of mechanical apparatus, the limitation is the speed at which one is able to actuate the necessary shuttering mechanism. In the case of electronic means, due to their complex scaling of the modulators to sufficient image resolution is difficult and costly.

## 15 SUMMARY OF THE INVENTION

[0009] In a preferred embodiment, the present invention is a system and method for high-resolution imaging terahertz radiation utilizing a spatial terahertz modulator based on interactions of photons at other energies with an intermediate screen to create very high speed modulation. This can be operated in either a passive imaging mode or a structured  
20 illumination (active) mode.

[0010] The present invention is a tremendous improvement on previous techniques in the ease of implementation as well as the capability to achieve very high resolution images

with a simplified terahertz modulator comprised only of a slab of appropriate materials and any traditional optical modulator such as liquid crystal or micromirrors.

[0011] In a preferred embodiment, the present invention is a system for high resolution imaging an object that is either reflecting or emitting terahertz radiation. The system comprises a source of visible light, a spatial modulator onto which said visible light is focused to produce patterned visible light, a screen where said patterned visible light is focused, a lens to focus terahertz radiation passing through said screen, a detector to collect terahertz radiation passing through said screen, and a computer equipped with an algorithm to reconstruct an image from a series of signals generated at said detector by said terahertz radiation passing through said screen. The screen comprises a material having a plurality of electronic states wherein focusing of said patterned light onto said screen changes an electronic state of said material such that said material becomes one of transparent or absorbing to terahertz radiation. The screen material may become absorbing of terahertz radiation upon illumination with visible light. The spatial light modulator may comprise, for example, a digital micromirror device, may be based on liquid crystals, or may comprises a mechanical spinning disk.

[0012] In another preferred embodiment, the present invention is a method for high resolution imaging of an object that is either reflecting or emitting terahertz radiation. The method comprises the steps of illuminating said object with a source of light, modulating said light with a spatial modulator onto which said light is focused to produce patterned light, screening said patterned light with a screen onto which said patterned light is focused, focusing terahertz radiation passing through said screen, collecting terahertz radiation passing through said screen with a detector, and reconstructing an

image from a series of signals generated at said detector by said terahertz radiation passing through said screen with a computer equipped with a reconstruction algorithm. The screen comprising a material having a plurality of electronic states wherein focusing of said patterned light onto said screen changes an electronic state of said material such that said material becomes one of transparent or absorbing to terahertz radiation. The source of light may comprise, for example, a source of visible light, infrared light, or structured terahertz light.

[0013] In another preferred embodiment, the present invention is a method for high resolution imaging of terahertz radiation. The method comprises the steps of modulating an incident light field by a series of patterns utilizing a spatial terahertz modulator based on interactions of photons at other energies with an intermediate screen to create very high speed modulation.

[0014] In another preferred embodiment, the present invention is a method for high-resolution imaging in other bands of the electromagnetic spectrum utilizing a photopatterned intermediate modulator. In yet another embodiment of the present invention, the present invention is a method for high-resolution ion and electron imaging comprising the steps of modulating an incident light field utilizing an intermediate modulator where photoexcitation liberates charged particles, focusing said liberated charged particles and collecting the liberated charged particles.

[0015] Still other aspects, features, and advantages of the present invention are readily apparent from the following detailed description, simply by illustrating a preferable embodiments and implementations. The present invention is also capable of other and different embodiments and its several details can be modified in various obvious respects,

all without departing from the spirit and scope of the present invention. Accordingly, the drawings and descriptions are to be regarded as illustrative in nature, and not as restrictive. Additional objects and advantages of the invention will be set forth in part in the description which follows and in part will be obvious from the description, or may be  
5 learned by practice of the invention.

#### BRIEF DESCRIPTION OF THE DRAWINGS

[0016] For a more complete understanding of the present invention and the advantages thereof, reference is now made to the following description and the accompanying drawings, in which:

10 [0017] FIG. 1A is a diagram of an imaging system in accordance with a preferred embodiment of the present invention.

[0018] FIG. 1B is a diagram of a compressive imaging device.

[0019] FIG. 2A is a diagram illustrating two spinning disks covered with enough adsorbing/scattering area in accordance with a preferred embodiment of the present  
15 invention so that the overlap in the image plane designated by the square box leads to approximately 50% attenuation of the signal at the detector.

[0020] FIG. 2B is a diagram illustrating an individual wheel of the two where the image plane is rotated 45 degrees so that its diagonal aligns radially with the disk, which would minimize the footprint of the overall device and maximize the patterns on the wheel.

20 [0021] FIG. 3 is a diagram illustrating almost the complete minimal footprint of the device by having both disks with their spindles aligned but still spinning at different speeds in accordance with a preferred embodiment of the present invention. This also



allows the opportunity to add more image planes in the other space and thus more sensors.

[0022] FIG. 4 is a diagram where the overlap of the image planes of the two discs are perpendicular to each other in accordance with a preferred embodiment of the present invention, allowing for maximum entropy in the combination of the partial patterns.

[0023] FIG. 5A is a side view of an embodiment of the present invention in which the disc system is replaced with two nested cylinders.

[0024] FIG. 5B is a top view of an embodiment of the present invention in which the disc system is replaced with two nested cylinders.

[0025] FIG. 6 is a diagram of a pair of tapes moving orthogonal to each other in accordance with another preferred embodiment of the present invention.

[0026] FIG. 7 is a diagram showing individual masks with partial patterns that may be translated horizontally, vertically, and depthwise relative to each other in various preferred embodiments of the present invention.

#### DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0027] A preferred embodiment of the present invention relies on a change in opacity of a screen material in the terahertz range that is modulated by electromagnetic radiation at other frequencies such as in the visible, ultraviolet, or infrared through the use of modulators such as the digital micromirror device. As shown in FIG. 1A. the system is comprised of a terahertz light source 102, a visible or infrared light source 112, a spatial light modulator such as the DMD 142, a patterned source of visible light resulting from its reflection off of the spatial light modulator 106, a screen composed of a material

whose absorption or transparency of terahertz can be altered by illumination or heating 162, and the resulting modulated pattern of terahertz radiation 164. The terahertz light can be generated by or reflected off an on object and after being modulated by the screen 162 can then be collected by a single detector and reconstructed into an image using the 5 discussed compressive sensing algorithms. Conversely, the terahertz radiation pattern can illuminate an object in a structured illumination manner after passing through the screen and the resulting reflected terahertz light can be collected by a single detector and reconstructed by previously discussed compressive sensing algorithms. Examples of screen materials for this method include a film of single walled nanotubes (See Chemical 10 Physics Letters 410 (2005) 298-301), conducting polymers or vanadium oxide film coated with a coating that is strongly absorbing at the non-terahertz frequency that would generate localized heating subsequently changing the properties at terahertz frequencies. Additionally any material with the population of electrons at the appropriate energy levels can lead to electron concentration enhancement or electron concentration depletion 15 which would then serve as an appropriate modulation material. In either case a change in the appropriate carrier concentration, rate of electron-hole recombination, or a phase-change of the interaction photon, accomplished through either optical promotion or thermal excitation would yield a large change in the terahertz transparency of the screen thus making it an appropriate shutter for photoinduced absorption or photoinduced 20 transparency mode. In addition, this phenomenon would be easily scaled to very small or very large sizes since the limitation on such is the focusing of the optical beam not the terahertz one.

[0028] Various uses of the present invention will be apparent to those of skill in the art. For example, imaging devices in accordance with the present invention could be utilized in airport security for scanning luggage and passengers. Additionally it could be extended to medical imaging or any applications where imaging by exposure to electromagnetic radiation is employed.

[0029] While extremely beneficial in creating a compressive sensing modulator for the terahertz frequency domain. Such a system can also be implemented in a wide variety of bands throughout the electromagnetic spectrum. The only requirement being that the patterned light is able to manipulate the electron density in the appropriate manner to either create sufficient conditions for photo-induced absorption or photo-induced transparency at the screen.

[0030] An example of a digital micromirror device (DMD) used with compressive sensing is described in U.S. Patent Application Publication No. 2006/0239336, which is hereby incorporated by reference in its entirety. That published application disclosed a camera architecture that uses for random measurements a digital micromirror array to spatially modulate an incident image and reflecting the result to a lens, which focuses the light to a single photodiode for measurement. Mathematically, such measurements correspond to inner products of the incident image with a sequence of pseudorandom patterns. For an image model the system assumes sparsity or compressibility; that is, that there exists some basis, frame, or dictionary (possibly unknown at the camera) in which the image has a concise representation. For reconstruction, the system and method uses the above model (sparsity/compressibility) and some recovery algorithm (based on optimization, greedy, iterative, or other algorithms) to find the sparsest or most

compressible or most likely image that explains the obtained measurements. The camera, however, did not have to rely on reflecting light off a digital micromirror device. The concept is that it can be based on any system that is capable of modulating the incident light field  $x$  (be it by transmission, reflection, or other means) by some series of patterns

5  $\phi_m$  and then integrating this modulated light field at a number of points to compute the inner products  $y(m) = \langle x, \phi_m^T \rangle$  between the light field and the series of patterns (the so-called “incoherent projections”  $y = \Phi x$  described below). From these inner products one can recover the original signal (with fewer inner products than the number of pixels ultimately reconstructed). Examples of systems that can modulate light fields include

10 digital micromirror devices (DMD), LCD shutter arrays (as in an LCD laptop projector), physically moving shutter arrays, any material that can be made more and less transparent to the light field of interest at different points in space, etc.

[0031] The DMD may comprise, for example, a 1024x768 array of electrostatically actuated micromirrors where each mirror of the array is suspended above an individual

15 SRAM cell. Each mirror rotates about a hinge and can be positioned in one of two states (+12 degrees and -12 degrees from horizontal); thus light falling on the DMD may be reflected in two directions depending on the orientation of the mirrors. Note that the Texas Instruments DMD is one possible embodiment, but many additional embodiments are possible.

20 [0032] With the help of a biconvex lens or other light collecting element, the desired image is formed on the DMD plane; this image acts as an object for a second biconvex lens, or re-imaging lens, which focuses the image onto a photodiode. The light is collected from one of the two directions in which it was reflected (e.g., the light reflected

by mirrors in the +12 degree state). The light from a given configuration of the DMD mirrors is summed at the photodiode to yield an absolute voltage that yields a coefficient  $y(m)$  for that configuration. The output of the photodiode is amplified through an op-amp circuit and then digitized by an analog to digital converter.

5    [0033] In the present invention an individual light modulator, such as DMD, may be replaced with various schemes of multilayered modulators to ease the system fabrication, to present a more universal modulation system applicable across the entire electromagnetic spectrum, and to preserve still the benefits of imaging by compressive sensing as previously described. Various schemes are disclosed in co-pending PCT  
10   Application Serial No. PCT/US2010/059343, which is hereby incorporated by reference in its entirety. Such a system having multilayered modulators is realizable due to the pseudorandom nature of the patterns employed. The image can be reconstructed, exactly or approximately, from the random projections by using a model, in essence to find the best or most likely image (in some metric) among all possible images that could have  
15   given rise to those same measurements.

[0034] Two or more masks whose combined attenuation, whether through transmission or reflection, will result in 50% blocking of the light at the detector in a knowable and controllable manner may be employed in either an additive sense in the case of transmissive modulation or in a multiplicative manner in the case of reflective  
20   modulation. Once a series of coefficients is assembled from shifting of these masks relative to each other and the detector is obtained, an image can be reconstructed from these compressed measurements. Such a scheme could be realized in many different ways for both binary and Gaussian modulators. Although not limited to the following,

some examples outlined below include interdigitated spinning disks, rotating concentric cylinders, and laterally translated planar sheets or tapes. The choice of the material in all cases can be optimized for that particular sensor/detector whether capturing images formed by various portions of the electromagnetic spectrum or, in the case of transmission, also include images formed by but not limited to particles such as electrons and neutrons. The mask can be placed in many possible locations in the optical path including but not limited to the image plane, lens plane, or lens focus. This is a method that is only amenable to compressive sensing based on random or pseudo-random patterns and is not feasible in imaging schemes that employ transform coding. The various compressive imaging systems discussed below directly acquire a reduced set of M incoherent projections of an N-pixel image  $x$  without first acquiring the N pixel values.

[0035] This compressive imaging system directly acquires a reduced set of M incoherent projections of an N-pixel image  $x$  without first acquiring the N pixel values. Since the camera is “progressive,” better quality images (larger K) can be obtained by taking a larger number of measurements M. Also, since the data measured by the camera is “future-proof,” new reconstruction algorithms based on better sparsifying image transforms can be applied at a later date to obtain even better quality images.

[0036] The recovery of the sparse set of significant coefficients  $\{\theta(n)\}$  can be achieved using optimization or other algorithms by searching for the signal with  $l_0$ -sparsest coefficients  $\{\theta(n)\}$  that agrees with the M observed measurements in  $y$  (recall that typically  $M < N$ ). That is, we solve the optimization problem

$$\theta_r = \operatorname{argmin} \|\theta\|_0 \text{ such that } y = \Phi\Psi\theta.$$

The  $l_0$  norm  $\|\theta\|_0$  counts the nonzero entries in the vector  $\theta$ ; hence it is a measure of the degree of sparsity, with more sparse vectors having smaller  $l_0$  norm.

[0037] Unfortunately, solving this optimization problem is prohibitively complex and is believed to be NP-hard (see Candès, E., Tao, T., “Error correction via linear programming,” (2005) Preprint). The practical revelation that supports the new CS theory is that it is not necessary to solve the  $l_1$ -minimization problem to recover the set of significant  $\{\theta(n)\}$ . In fact, a much easier problem yields an equivalent solution (thanks again to the incoherency of the bases); we need only solve for the  $l_1$ -sparsest coefficients  $\theta$  that agree with the measurements  $y$

$$\theta_r = \operatorname{argmin} \|\theta\|_1 \text{ such that } y = \Phi\Psi\theta. \quad (2)$$

[0038] The optimization problem (2), also known as Basis Pursuit (see Chen, S., Donoho, D., Saunders, M., “Atomic decomposition by basis pursuit,” SIAM J. on Sci. Comp. 20 (1998) 33–61), is significantly more approachable and can be solved with traditional linear programming techniques whose computational complexities are polynomial in  $N$ . Although only  $K+1$  measurements are required to recover sparse signals via  $l_0$  optimization, one typically requires  $M \sim cK$  measurements for Basis Pursuit with an overmeasuring factor  $c > 1$ .

[0039] We use the notation  $c$  to describe the overmeasuring/oversampling constant required in various settings and note the following approximation: The constant  $c$  satisfies  $c \approx \log_2 (1 + N/K)$ .

[0040] While reconstruction based on linear programming is one preferred embodiment, any reconstruction approach can be used in the present invention. Other examples include the (potentially more efficient) iterative Orthogonal Matching Pursuit (OMP) (see Tropp,

J., Gilbert, A.C., "Signal recovery from partial information via orthogonal matching pursuit," (2005) Preprint), matching pursuit (MP)(see Mallat, S. and Zhang, Z., "Matching Pursuit with Time Frequency Dictionaries", (1993) IEEE Trans. Signal Processing 41(12): 3397--3415), tree matching pursuit (TMP) (see Duarte, M.F., Wakin, M.B., Baraniuk, R.G., "Fast reconstruction of piecewise smooth signals from random projections," Proc. SPARS05, Rennes, France (2005)) algorithms, group testing (see Cormode, G., Muthukrishnan, S., "Towards an algorithmic theory of compressed sensing," DIMACS Tech. Report 2005-40 (2005) , Sudocodes (see U.S. Provisional Application Serial No. 60/759,394 entitled "Sudocodes: Efficient Compressive Sampling Algorithms for Sparse Signals," and filed on January 16, 2006), or statistical techniques such as Belief Propagation, (see Pearl, J., "Fusion, propagation, and structuring in belief networks", (1986) Artificial Intelligence, 29(3): 241--288), LASSO (see Tibshirani, R., "Regression shrinkage and selection via the lasso", (1996) J. Royal. Statist. Soc B., 58(1): 267--288), LARS (see Efron, B., Hastie, T., Johnstone, I., Tibshirani, R., "Least Angle Regression", (2004) Ann. Statist. 32(2): 407--499), Basis Pursuit with Denoising (see Chen, X., Donoho, D., Saunders, M., "Atomic Decomposition by Basis Pursuit", (1999), SIAM Journal on Scientific Computing 20(1): 33--61), expectation-maximization (see Dempster, Laird, N., Rubin, D., "Maximum likelihood from incomplete data via the EM algorithm", (1997) Journal of the Royal Statistical Society, Series B, 39(1): 1--38), and so on. These methods have also been shown to perform well on compressible signals, which are not exactly K-sparse but are well approximated by a K-term representation. Such a model is more realistic in practice.



[0041] Reconstruction can also be based on other signal models, such as *manifolds* (see Wakin, M, and Baraniuk, R., “Random Projections of Signal Manifolds” IEEE ICASSP 2006, May 2006, to appear). Manifold models are completely different from sparse or compressible models. Reconstruction algorithms in this case are not necessarily based on sparsity in some basis/frame, yet signals/images can be measured using the systems described here.

[0042] The preferred embodiment is to reconstruct an N-pixel image or video sequence from  $M < N$  measurements. Additional embodiments using more measurements are possible. For example, if we use  $M = N$  or  $M > N$  measurements, then the extra measurements can be used for subsequent processing. For example, additional measurements may be used for averaging or filtering when the image is noisy or corrupted in some way.

[0043] FIG. 1B shows a compressive imaging (CI) device or system. An incident light field 110 corresponding to the desired image  $x$  passes through a lens 120 and is then reflected off a digital micromirror device (DMD) array 140 whose mirror orientations are modulated in the pseudorandom pattern sequence supplied by the random number generator or generators 130. Each different mirror pattern produces a voltage at the single photodiode detector 160 that corresponds to one measurement  $y(m)$ . While only one photodetector is shown in FIG. 1, any number of detectors may be used, although typically, the number of photodetectors will be less than the total number of ultimate number of pixels obtained in the image. The voltage level is then quantized by an analog-to-digital converter 170. The bitstream produced is then communicated to a reconstruction algorithm 180, which yields the output image 190.

[0044] Various possible modulation schemes are described below with reference to FIGs. 2-8. For purposes of simplicity, most of FIGs. 2-8 only illustrate two layers but it will be understood by those of skill in the art that the principal is easily extended to more than two.

5 [0045] As shown in FIG. 2A, in a preferred embodiment of the present invention the CI camera has a multilayered modulator 200 in the form of two spinning disks 210, 220 that are covered with enough adsorbing/scattering area so that the overlap in the image plane designated by the square box 230 leads to approximately 50% attenuation of the signal at the detector. To minimize the correlation of the combined patterns the two disks 210, 220  
10 should be rotating at different speeds such as 3333 Hz and 5000 Hz. The appropriate choice of the speeds could also maximize the number of patterns before repetition begins. The solid lines 240, 250 represent synchronization points on the wheel determined either optically or by a non-optical method such as placement of a small magnet on the disk and the inclusion of a nearby Hall-effect sensor.

15 [0046] Thus, in a preferred embodiment of the present invention, a multilayered modulator comprising a plurality of discs, such as are shown in FIG. 2A, modulate an incident light field by a series of patterns to produce a voltage or voltages at a detector or detectors. By using an appropriate material for the screen or disc as described previously, a change in the appropriate carrier concentration through either optical promotion or  
20 thermal excitation would yield a large change in the terahertz transparency of the screen or disc thus making it an appropriate shutter for photoinduced adsorption or photoinduced transparency mode.

[0047] The detector measurements can be interpreted as optically computed inner products between the light field and the series of patterns. A processor (item 180 in FIG. 1B) recovers the signal based upon the inner products and an algorithm. The algorithm may be, for example, at least one of a Greedy reconstruction algorithm, Matching Pursuit, Orthogonal Matching Pursuit, Basis Pursuit, group testing, LASSO, LARS, expectation-maximization, Bayesian estimation algorithm, belief propagation, wavelet-structure exploiting algorithm, Sudocode reconstruction, reconstruction based on manifolds,  $l_1$  reconstruction,  $l_0$  reconstruction, and  $l_2$  reconstruction.

[0048] Variations in the arrangements of the discs in the multilayer modulator may be used. In FIG. 2B, the image plane 230 of an individual wheel or disk 210 of two disks such as are shown in FIG. 2A is rotated 45 degrees so that its diagonal aligns radially with the disk, which would minimize the footprint of the overall device and maximize the patterns on the wheel 230. FIG. 3 is a diagram showing an embodiment having an almost complete minimal footprint by having both disks 310, 320 with the spindles 302, 304 aligned but still spinning at different speeds. This also allows the opportunity to add more image planes 330 in the other space and thus more sensors. FIG. 4 is a diagram where the overlapping image planes of the two discs 410, 420 are perpendicular to each other, allowing for maximum entropy in the combination of the partial patterns.

[0049] Other embodiments may incorporate multilayered modulators other than discs.

FIGs. 5A and 5B illustrate another embodiment of the present invention in which the disc system of FIG. 2A is replaced with multilayered modulator 500, which has with two nested cylinders 510, 520 having image planes 512 and 522. In the embodiment shown

in FIG. 6, modulation is accomplished with a pair of tapes 610, 620 moving orthogonal to each other rather than with a pair of discs.

[0050] Further, FIG. 7 illustrates a plurality of individual masks 710, 720, 730, 740 and 750, with partial patterns that may be translated horizontally, vertically, and depthwise relative to each other in various embodiments. Their motion could be controlled by many different means one example is to employ piezoelectric transducers.

[0051] The foregoing description of the preferred embodiment of the invention has been presented for purposes of illustration and description. It is not intended to be exhaustive or to limit the invention to the precise form disclosed, and modifications and variations are possible in light of the above teachings or may be acquired from practice of the invention. The embodiment was chosen and described in order to explain the principles of the invention and its practical application to enable one skilled in the art to utilize the invention in various embodiments as are suited to the particular use contemplated. It is intended that the scope of the invention be defined by the claims appended hereto, and their equivalents. The entirety of each of the aforementioned documents is incorporated by reference herein.

## CLAIMS

What is claimed is:

1. A system for high resolution imaging an object that is either reflecting or emitting terahertz radiation comprising:

5 a source of visible light;

a spatial modulator onto which said visible light is focused to produce patterned visible light;

a screen where said patterned visible light is focused, said screen comprising a material having a plurality of electronic states wherein focusing of said patterned light  
10 onto said screen changes an electronic state of said material such that said material becomes one of transparent or absorbing to terahertz radiation;

a lens to focus terahertz radiation passing through said screen;

a detector to collect terahertz radiation passing through said screen; and

a computer equipped with an algorithm to reconstruct an image from a series of  
15 signals generated at said detector by said terahertz radiation passing through said screen.

2. A system for high resolution imaging according to claim 1 wherein said screen material becomes absorbing of terahertz radiation upon illumination with visible light.

3. A system for high resolution imaging according to claim 1 wherein said  
20 spatial light modulator comprises a digital micromirror device.

4. A system for high resolution imaging according to claim 1 wherein said spatial light modulator is based on liquid crystals.

5. A system for high resolution imaging according to claim 1 wherein said

spatial light modulator comprises a mechanical spinning disk

6. A system for high resolution imaging an object that is either reflecting or emitting terahertz radiation comprising the steps of:

a source of infrared light;

5 a spatial modulator onto which said infrared light is focused to produce patterned infrared light;

a screen where said patterned infrared light is focused, said screen comprising a material having a plurality of electronic states wherein focusing of said patterned light onto said screen changes an electronic state of said material such that said material

10 becomes one of transparent or absorbing to terahertz radiation;

a lens to focus terahertz radiation passing through said screen;

a detector to collect terahertz radiation passing through said screen; and

a computer equipped with an algorithm to reconstruct an image from a series of signals generated at said detector by said terahertz radiation passing through said screen.

15 7. A method for high resolution imaging of an object that is either reflecting or emitting terahertz radiation comprising:

illuminating said object with a source of light;

modulating said light with a spatial modulator onto which said light is focused to produce patterned light;

20 screening said patterned light with a screen onto which said patterned light is focused, said screen comprising a material having a plurality of electronic states wherein focusing of said patterned light onto said screen changes an electronic state of said material such that said material becomes one of transparent or absorbing to terahertz

radiation;

focusing terahertz radiation passing through said screen;

collecting terahertz radiation passing through said screen with a detector; and

reconstructing an image from a series of signals generated at said detector by said

5 terahertz radiation passing through said screen with a computer equipped with a  
reconstruction algorithm.

8. A method for high resolution imaging of an object according to claim 7,  
wherein said source of light comprises a source of visible light.

9. A method for high resolution imaging of an object according to claim 7,  
10 wherein said source of light comprises a source of infrared light.

10. A method for high resolution imaging of an object according to claim 7,  
wherein said source of light comprises a source of structured terahertz light.

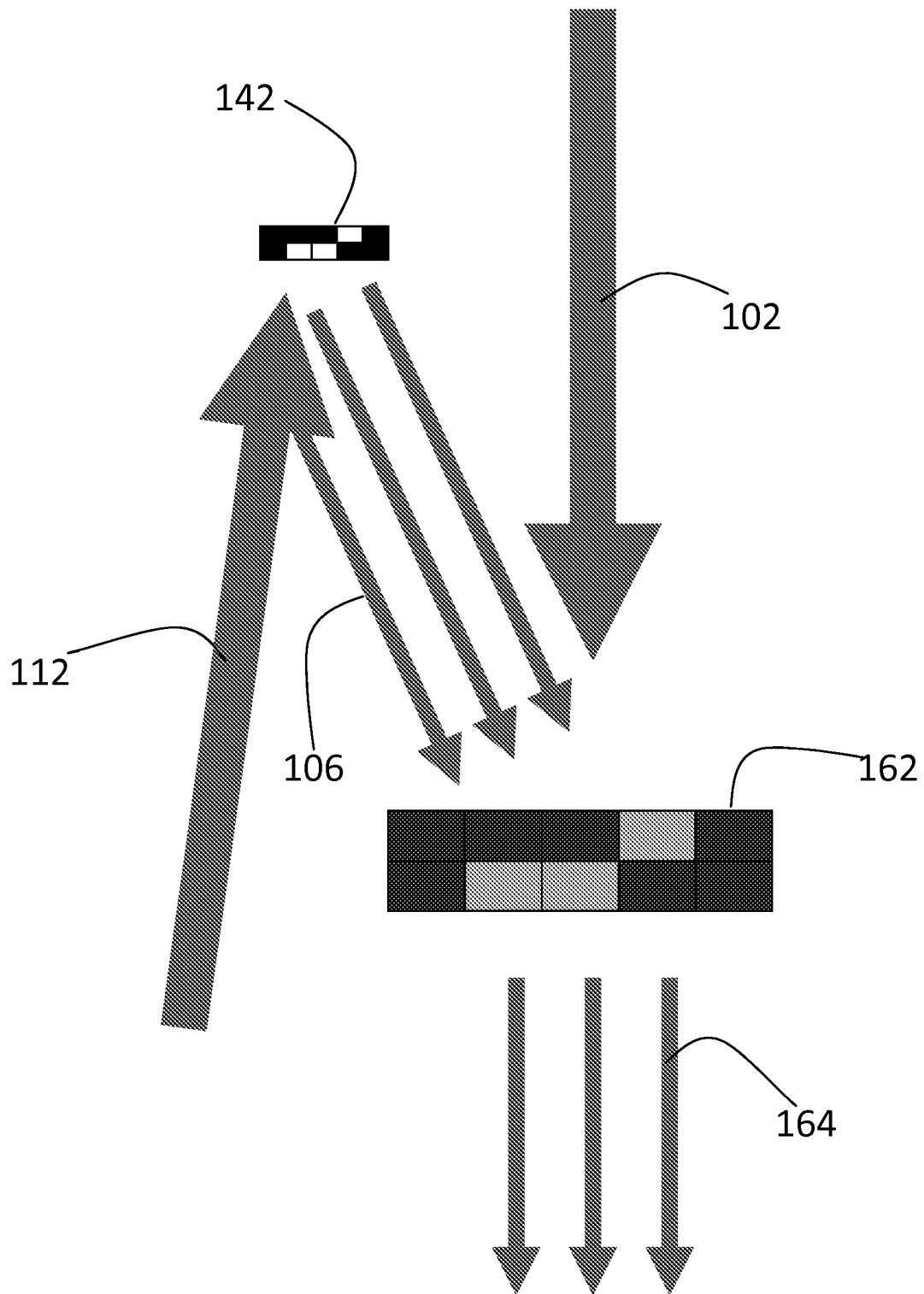


FIG. 1A



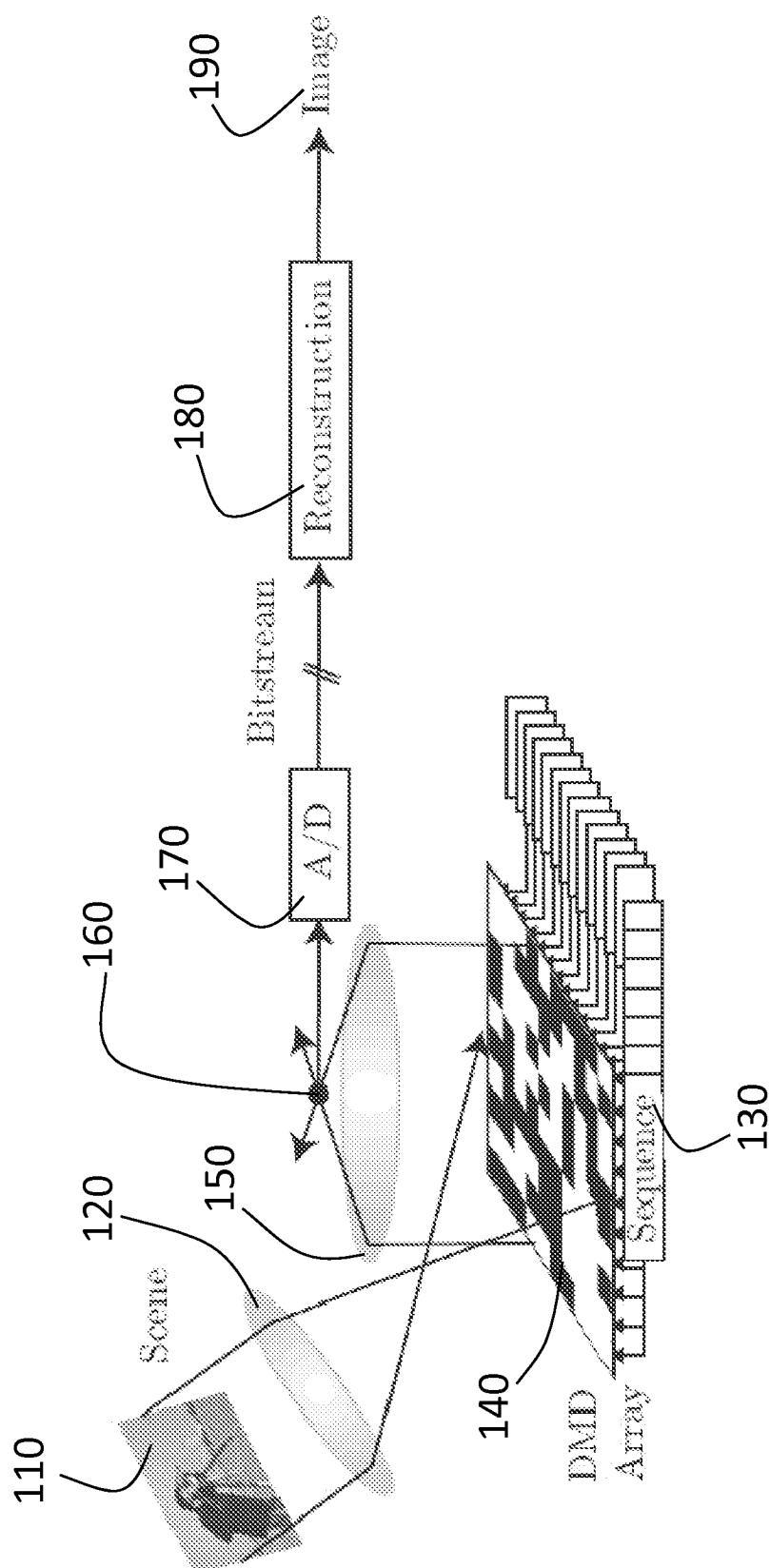
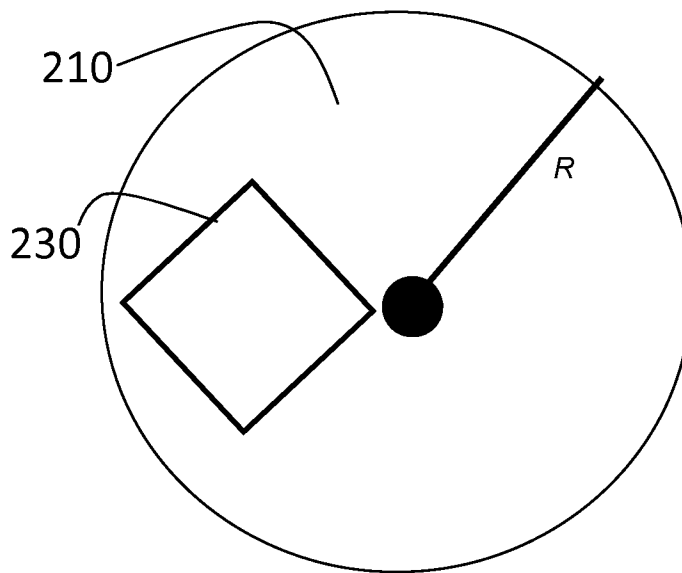
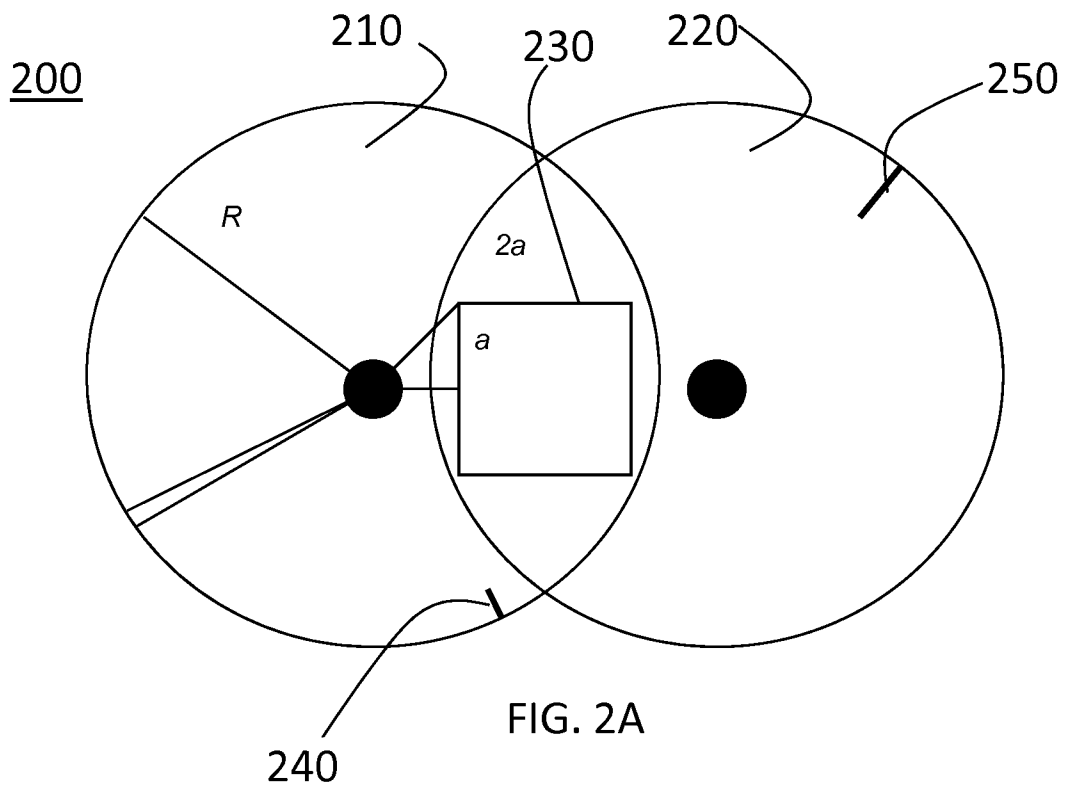


FIG. 1B



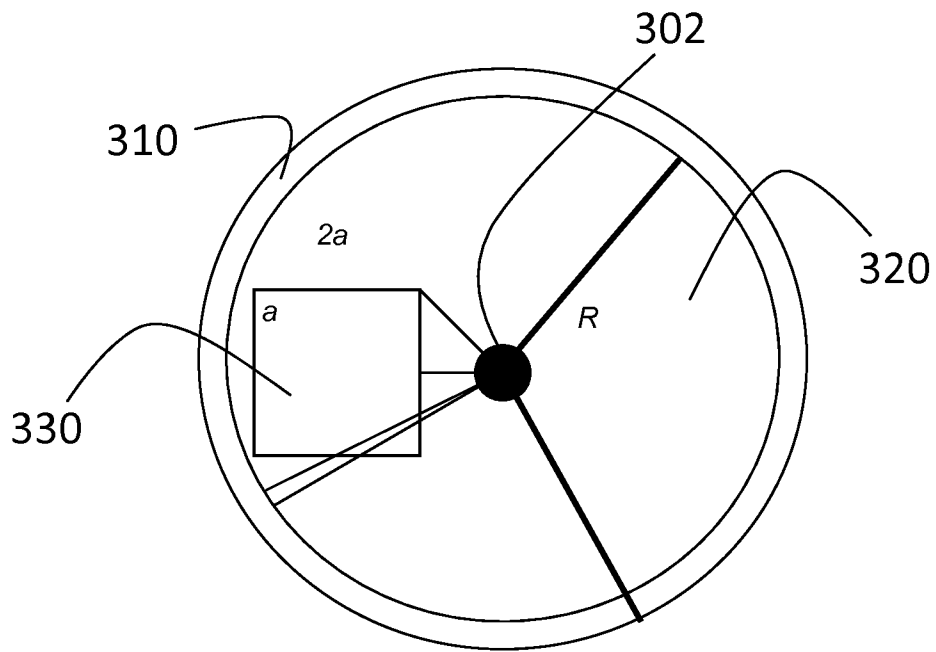


FIG. 3

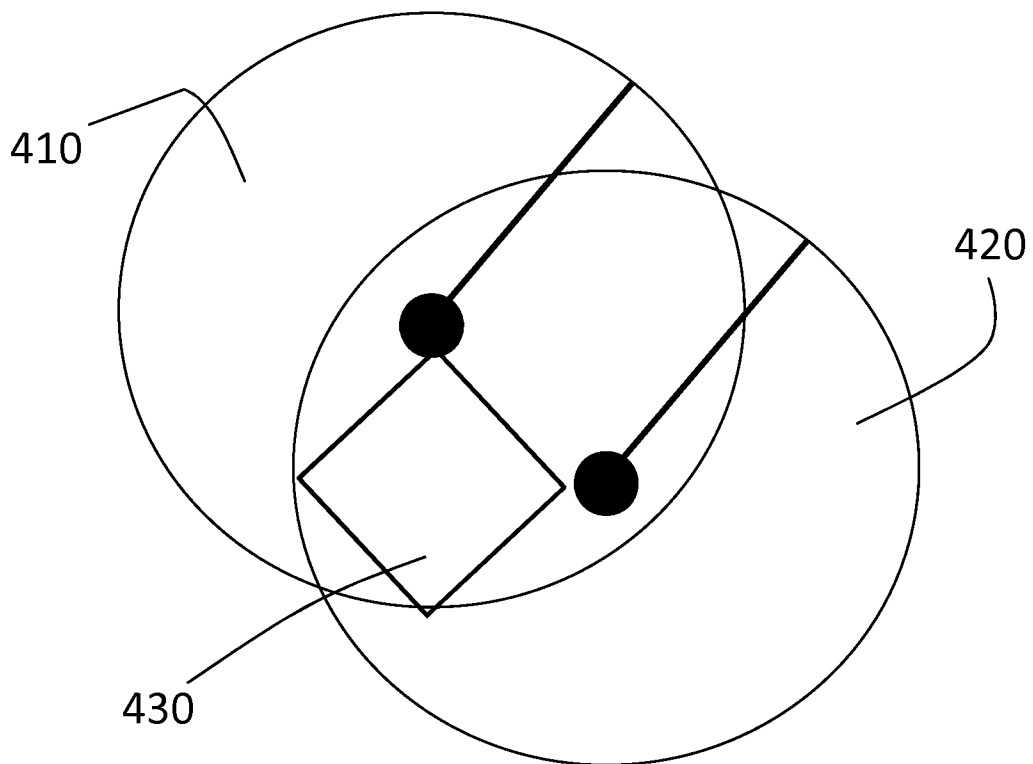


FIG. 4

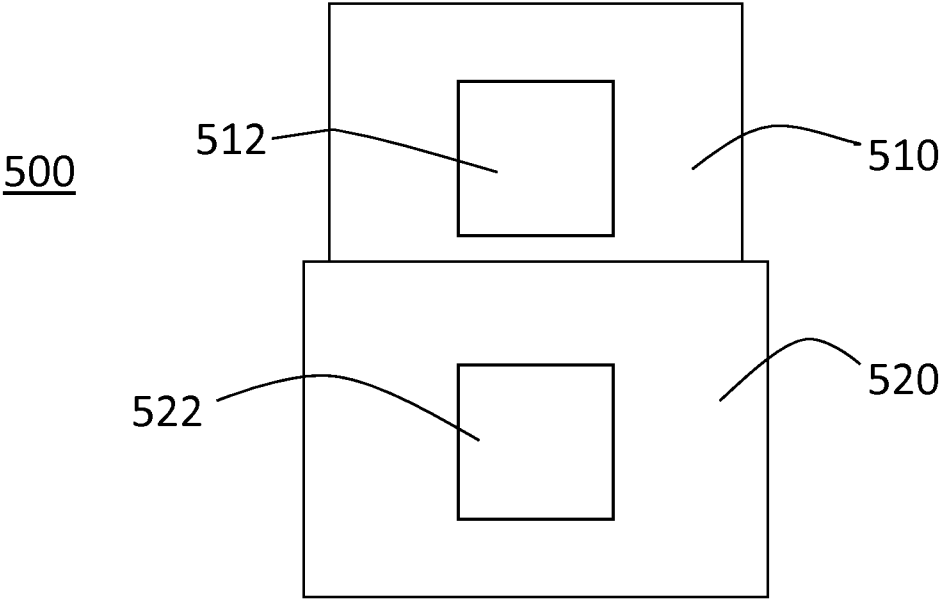


FIG. 5A

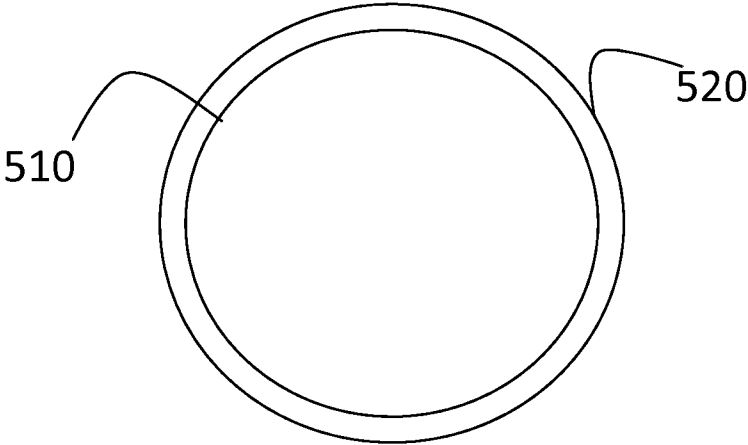


FIG. 5B

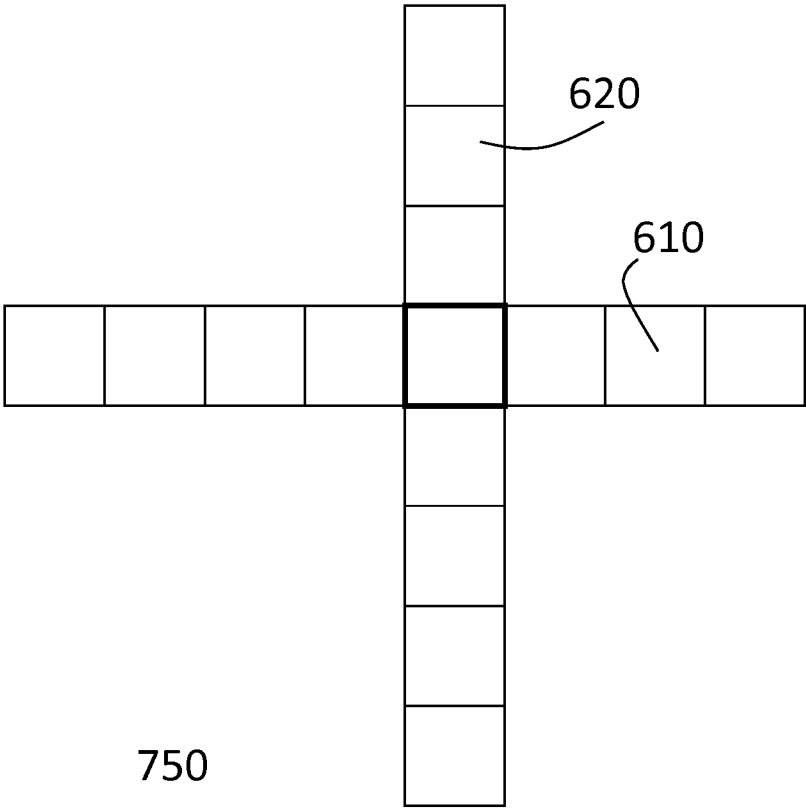


FIG. 6

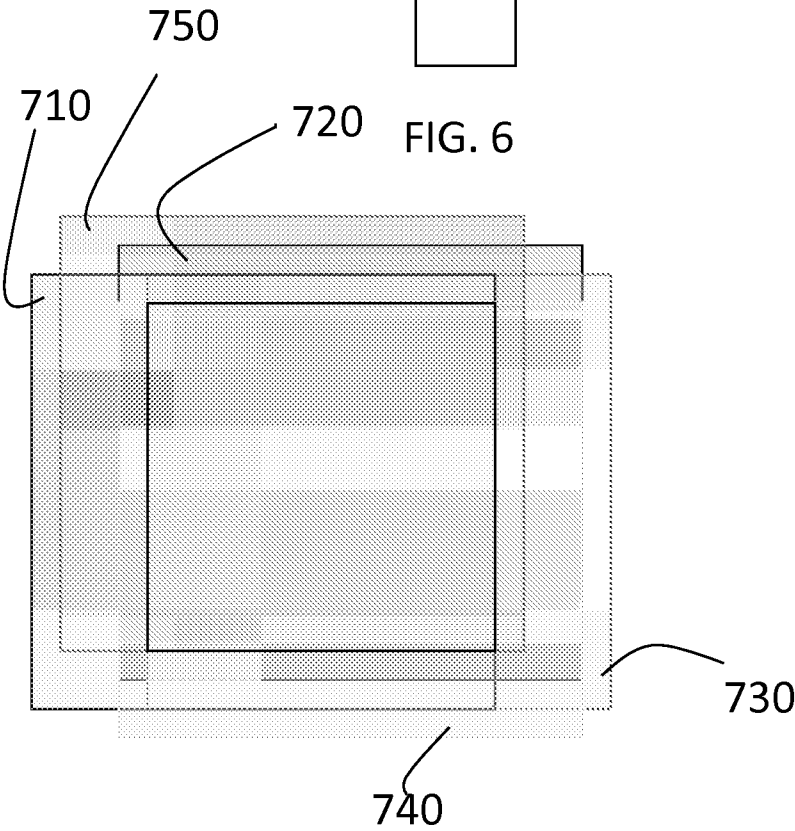


FIG. 7