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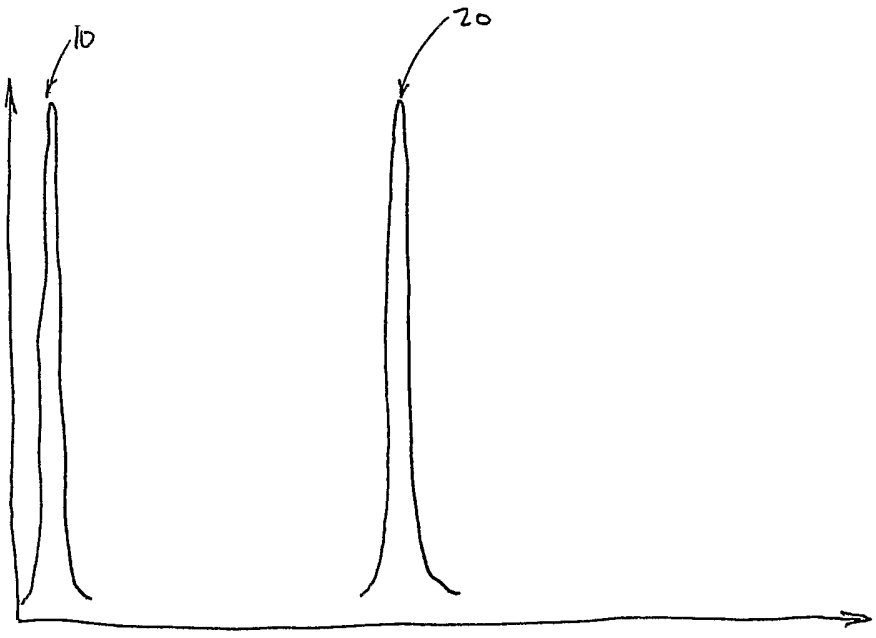
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(54) Title: METHOD AND APPARATUS FOR RADIATION IMAGE ERASURE



(57) Abstract: Methods and device are provided for improved storage screen erasure. A storage screen erasure device comprises a first wavelength source and a second wavelength source. The first wavelength may be selected to pump signal on the screen to be more easily erased by said second wavelength source. The sources may direct energy sequentially onto the screen, it may occur simultaneously, or any combination of the two.

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PATENT

METHOD AND APPARATUS FOR RADIATION IMAGE ERASURE

BACKGROUND OF THE INVENTION

Field of the Invention

This invention relates to radiographic imaging and more specifically to image data related to computed radiography.

Description of Related Art

The use of photo-stimulable phosphor image storage screens as a replacement for X-ray film and other sensors is well known. Phosphor image screens work by trapping electrical charge in response to exposure to x-ray radiation. The trapped charge represents a latent image of the x-ray radiation pattern. This latent image can then be read by scanning the storage layer using a suitable wavelength excitation beam, preferably from a focused laser. The laser excitation beam causes the screen to release the trapped electrical charge in the form of emitted stimulable phosphor light that is proportional to the X-ray energy applied to the screen during exposure. The emitted light is collected by an optical system and is converted into an electronic signal proportional to the emitted light. The electrical signal is then converted to a digital value and passed to a computer that generates and stores an image file. The image file can then be displayed as a representation of the original radiograph, with image enhancement software applied to augment the radiographic information.

Latent images stored on a storage layer radiation screen are usually erased prior to placing the storage layer radiation screen back into use. There are a variety of known methods for erasing this latent image. For example, Molecular Dynamics discloses the use of a 500 W photoflood tungsten light bulb and a yellow filter with 10 J/cm^2 exposure to reduce latent image or residual signal levels to less than 10^{-5} of the original exposure level.

Unfortunately, many known methods of erasure are inefficient and have drawbacks that constrain the size, energy consumption, and reliability of the devices used to erase storage layer radiation screens.

SUMMARY OF THE INVENTION

Accordingly, an object of the present invention is to provide improved storage layer radiation erasing systems, and their methods of use.

Another object of the present invention is to provide improved image erasing techniques which reduces the intensity required to erase an image.

Another object of the present invention is to provide improved image erasing techniques which more thoroughly erases images from a storage medium.

Yet another object of the present invention is to provide improved erasing device and their methods of use, that allow for higher throughput of image storage screens through an erasing device.

Still a further object of the present invention is to provide a storage phosphor system, and the methods of use, that use an improved image erasing scheme.

Another object of the present invention is to integrate an improved erasing assembly with a multiple head storage phosphor system. The integration may result in a single device that moves an image screen inside the device from a read position to an erase position.

At least some of these objects are achieved by some embodiments of the present invention.

In one aspect of the present invention, methods and device are provided for improved storage screen erasure. In one embodiment, a storage screen erasure device comprises a first wavelength source and a second wavelength source. The first wavelength may be selected to pre-excite ("pump") trapped charge to a state from which it may be more easily removed by a second ("erasing") wavelength. In another aspect of the present invention, a method for storage screen erasure is provided. The method comprises first exposing the screen to energy at a first wavelength to pump the charge to a more loosely bound state, and second, exposing the screen to energy at a second erasing wavelength to remove the trapped charge. In one embodiment, irradiation by the pumping wavelength occurs prior to irradiation by the erasing wavelength. In another embodiment, irradiation by the pumping wavelength and irradiation by the erasing wavelength occur simultaneously. In still further embodiments, the screen is exposed to energy at a third wavelength. A broadband source may be used in some embodiments. In other embodiments, a single source may be used that has a mix of the pumping wavelength and the erasing wavelength, whose relative intensities and total intensities

may be adjusted to optimize erasure for a given embodiment or storage phosphor formulation.

In another embodiment of the present invention, a storage screen erasure device is provided. The device comprises a plurality of LEDs providing energy at a first wavelength and a plurality of LEDs providing energy at a second wavelength. The first wavelength is selected to pump signal on the screen to be more easily erased by the second wavelength source. In one non-limiting example, the first wavelength is about 460 nm and the second wavelength is at about 640 nm.

In yet another embodiment of the present invention, an erasure device is provided which comprises a broadband wavelength source and a narrowband wavelength source at a pumping wavelength. The narrowband wavelength source may be selected to pump signal on the screen to be more easily erased by the broadband.

Finally, another embodiment might involve the adjustment of overall intensity, and /or the relative intensities of the multiple wavelengths, and / or the time duration that the storage phosphor imaging plate is exposed to the erasing light.

A further understanding of the nature and advantages of the invention will become apparent by reference to the remaining portions of the specification and drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 shows the stimulation spectrum an image storage screen.

Figures 2 and 3 show the output of various energy sources.

Figures 4 and 5 show perspective and cross-sectional views of one embodiment of an erasure device according to the present invention.

Figure 6 is a cross-sectional view of a further embodiment according to the present invention.

Figures 7-9 show other embodiments of energy sources according to the present invention.

Figures 10-12 show the order of energy source exposure according to the present invention.

Figure 13A is a top plan view of a first preferred embodiment of the present invention incorporating three radially extending optical trains mounted at 120.degree. to one another, with the "optical radius" (ie: the radial distance from the center of the

scanning device to the focal point of the laser beam under each scanning head) being 1.1547 times one-half the width of the phosphor screen.

Figure 13B is a top plan view of a second preferred embodiment of the present invention incorporating three radially extending optical trains mounted at 120.degree. to one another, with the optical radius being slightly greater than 1.1547 times one-half the width of the phosphor screen.

Figure 14 is a side sectional view taken along the line 2--2 in Figure 1A.

Figure 15 is an enlarged view of a portion of Figure 2.

Figure 16A is a schematic representation of the preferred optical train shown in Figure 3.

Figure 16B is a schematic representation of an alternative preferred optical train.

Figure 16C is a schematic representation of yet another preferred optical train.

Figure 16D is a schematic representation of an alternative preferred optical train.

Figure 16E is a schematic representation of yet another preferred optical train.

Figure 17 is a geometric representation of incremental movement of an arcuate line across the surface of a phosphor screen.

Figures 18A and 18B show a two head scanning device.

Figure 19 shows a four head scanning device.

Figure 20 shows a six head scanning device.

Figure 21 is a top plan view of an alternate arrangement of the present invention with the phosphor screen disposed perpendicular to the scanning device and partially wrapped around the perimeter of the scanning device.

Figure 22 is a cut away side view corresponding to Figure 9.

Figure 23 is an illustration of successive scans taken across the phosphor screen of Figure 21.

DESCRIPTION OF THE SPECIFIC EMBODIMENTS

It is to be understood that both the foregoing general description and the following detailed description are exemplary and explanatory only and are not restrictive of the invention, as claimed. It should be noted that, as used in the specification and the appended claims, the singular forms "a", "an" and "the" include plural referents unless the context clearly dictates otherwise. Thus, for example, reference to "a material" may include mixtures of materials, reference to "an LED" may include multiple LEDs, and the like. References cited herein are hereby incorporated by reference in their entirety,

except to the extent that they conflict with teachings explicitly set forth in this specification.

In this specification and in the claims which follow, reference will be made to a number of terms which shall be defined to have the following meanings:

"Optional" or "optionally" means that the subsequently described circumstance may or may not occur, so that the description includes instances where the circumstance occurs and instances where it does not. For example, if a device optionally contains a feature for analyzing a blood sample, this means that the analysis feature may or may not be present, and, thus, the description includes structures wherein a device possesses the analysis feature and structures wherein the analysis feature is not present.

The excitation spectrum associated with storage image screens such as, but not limited to, storage phosphor, may be quite broad. In general, the broad smooth excitation spectrum will have one or more excitation lines or specific wavelengths in the broad curve. In one aspect, the present invention describes the use of different excitation/erasure wavelengths within that spectrum, other than those centered on the red, to erase latent images. In another aspect, the present invention describes the combination of different wavelengths for erasure of latent images. In a still further aspect, the present invention describes the sequential use of different wavelengths to erase a latent image.

Referring now to Figure 1, a graph is presented that shows the stimulation spectrum for one embodiment of an image storage screen. In this particular embodiment, the spectrum is for a phosphor image screen which is barium based, with some strontium. The X-axis on the chart corresponds to stimulation wavelength while the Y-axis shows photo-stimulated luminescence (PSL) intensity. The curve C shows the intensity of emitted light when the screen is stimulated at different wavelengths. Lines 10, 12, 14, 16, 18, and 20 correspond to wavelengths about which various LEDs may be centered. Of course, LEDs with wavelengths centered about other wavelengths may also be used with the present invention.

Referring now to Figure 2, one embodiment of the present invention may use a plurality of wavelength sources to provide stimulation energy at specific wavelengths. It has been shown in the present invention that exposure of a storage screen to energy at a first (i.e. pumping) wavelength and then to energy at a second wavelength (i.e. the erasing wavelength) results in improved erasing efficiency as compared to the same total intensity at the erasing wavelength alone, for the same exposure time. As a non-limiting example,

a phosphor image screen such as but not limited to that whose excitation spectrum is shown in Figure 1 can achieve a higher erasure quality by first exposing the screen to energy at a blue visible wavelength centered at about 460 nm shown as position 10 in Figure 2. The screen is then exposed to energy at the erasure wavelength of 640 nm at position 20. The exposure to blue visible light pumps or excites the phosphor screen to an excitation state where trapped charge is more thoroughly erased by light or energy at the erasure wavelength.

In some embodiments, rather than sequentially exposing the image plate to the pumping wavelength and then to the erasing wavelength, both wavelengths may be applied simultaneously (see Figure 11). It should be understood, that in some further embodiments, three or more wavelengths may be used singly, in pairs, in other numbers, and may be applied in any combination of sequential or simultaneous exposures. In other embodiments, wavelengths different from those described above may also be used. In one non-limiting example, the first wavelength may be in the range of 400 to 640nm while the second wavelength may be in the range of 600 nm and longer.

Referring now to Figure 3, the graph of one embodiment of a broadband wavelength source having a tailored output is shown. The output has peaks at positions 10 and 20 which correspond to the pump and erasure wavelengths for a phosphor screen as described above. The broadband wavelength source may include, but is not limited to, an image eraser lamp such as, but not limited to, a tungsten light bulb. The lamps or bulbs may be used with various filters to create the desired output. Lamps or even broadband LEDs may also be manufactured to have specific output profiles.

Referring now to Figures 4 and 5, one embodiment of a device 30 according to the present invention will be described. Figure 4 shows a perspective view of an erasing device 30 where an imaging screen would enter as indicated by arrows 32 and exit as indicated by arrows 34. The device 30 may be coupled to a phosphor image reader device as disclosed in U.S. Patent Nos. 6,268,613 and 6,355,938 fully incorporated herein by reference (for the PCT guys, why can't we incorporate the PCT applications by reference as well, and obviate the need to include the patents (verbatim) in this application?). As seen in Figure 5, a plurality of printed circuit boards (PCBs) 40, 42, and 44 may have installed LEDs 46, 48, and 50. In one non-limiting example, the PCB 40 includes LEDs of one color such as but not limited to, blue. This PCB 40 with the blue LEDs will pump the stored charge to be more easily removed by the light from the LEDs

mounted on the next PCB (42). The PCB 42 includes a plurality of LEDs in the red wavelength. This PCB 42 emits energy that will erase the signal that has been pumped up by the blue-emitting LEDs on PCB 40. In one embodiment, the third PCB 44 may have mounted additional red LEDs to provide further erasing capability. In some further embodiments, each PCB 40, 42, and 44 may have LEDs of different wavelengths. Some embodiments may have two pumping boards and one erasing board. Still further embodiments may have at least one board where at least some of the LEDs are at a first wavelength while at least some of the other LEDs are at a second wavelength. Such a board may also include a third or higher number of wavelengths. It should also be understood that at least one of these boards may be replaced by a lamp or other broadband source and used in conjunction with sources such as but not limited to, LEDs which produce energy over specified wavelengths.

Referring now to Figure 6, yet another embodiment of the device 30 may include only two PCBs 40 and 42. In one non-limiting example, PCB 40 produces a pumping wavelength while the PCB 42 produces an erasing wavelength. Each of these wavelengths may be selected based on the type of storage screen being used. Some plates are stimulated in the infrared and emit in the green. So, the wavelengths for pumping and erasure may be dependent on the particular storage phosphor material used.

Referring now to Figure 7, one configuration of a board is shown where LEDs 50 of a first wavelength are shown with a hollow circle while LEDs 52 of a second wavelength are shown with a solid circle. In this embodiment, the LEDs may be distributed in an alternating pattern. This configuration supports an embodiment wherein the storage phosphor imaging plate is simultaneously exposed to pumping and erasing wavelengths.

Referring now to Figure 8, another configuration of a board shows an entire row of LEDs 50 and another row of LEDs 52. These may be in alternating rows, rows of one type of LEDs followed by a single row of the other type of LED, or any combination of rows.

Referring now to Figure 9, a still further embodiment shows boards or wavelength sources 54 and 56 joined by an optical coupler 58. Each board or source provides a different wavelength. They may be flashed in a sequence, activated simultaneously, or any combination of the above to provide pumping and erasing energy to an imaging plate 60.

Figures 10 through 12 show various combinations of the sequence of the energy sent to the imaging plate. Figure 10 shows a combination where the shorter wavelengths are used first , followed by longer wavelengths. Figure 11 shows that shorter and longer wavelengths are used simultaneously. Figure 12 shows a shorter wavelength source used simultaneously with a broadband wavelength source. In a still further embodiment, a energy source providing energy at a pumping wavelength for a specific screen material may be used in conjunction with a broadband source. Any of the combinations above may be used singly, in pairs, in other numbers, in sequence, simultaneously, or in any combination of the above to provide signal erasure.

It should be understood that the pumping wavelength, in one embodiment, may be in the blue, violet, and ultraviolet wavelengths. For the erasing wavelength, longer wavelengths ranging from green through infrared may be used. Accordingly, although one embodiment uses a 460nm source for pumping and a 640nm source for erasure, a variety of wavelengths maybe used such as but not limited to: 500 to 400nm for pumping and 600 to 750nmor longer wavelengths for erasure.

Embodiments of the present invention may also comprise one board having all of the pumping and erasure light sources on the same board. These light sources may also be, but are not necessarily, arranged on the board in some pattern such as but not limited to circles, polygons, triangles, squares or other shape as may be useful for extracting trapped charge from the imaging plate. In one embodiment, the present invention provides improved erasure and can provide a throughput of X meters per second due to the erasing efficiency of the combined wavelengths. Throughput may also be quantified as processing X image storage screens of size Y per minute. Such screen rates can be found with reference to the device shown in U.S. Patent No. 6,268,613 or U.S. Patent Application Ser. No. 09/847,857 (Attorney Docket No. 39315-0050) filed May 1, 2001. All applications and patents listed herein are incorporated herein by reference for all purposes. Known erasing systems may be able to achieve such an erasing efficiency, but would either need to move more slowly past the bank of eraser lights, require greater eraser intensity with the additional heat, or require larger banks of eraser lights.

LEDs are convenient to use in embodiments of the present invention since they require low voltage and are easy to implement. Silicon devices may also be used.

Embodiments of the present invention have been shown to provide up to a 50,000:1 erasure ratio. For single wavelength erasure schemes with similar total intensity,

erasure ratios of 10,000:1 or less are typical. Depending on the design tradeoffs that are made, the present invention can efficiently achieve essentially any desired depth of erasure.

Moreover, embodiments of the present invention have been shown to provide equivalent erasure for much less heat compared to erasure mechanisms that are extant.

The mounting means for the erasure lights may also be configured to be moveable, such as but not limited to, being on a track, pulley, conveyor system, or other moving device to move the erasure lights past the imaging plate. In some embodiments, the screen may remain stationary while the eraser assembly is moved. In other embodiments, the eraser assembly is stationary and the image plate is moved. In still further embodiments, both the erasure assembly and the image plate are in motion. Optical trains using prisms, splitters, mirrors, movable mirrors, rotating mirrors, or the like may also be used to disperse energy over desired areas of the screen.

Suitable Scanning Device

The present invention may be coupled with a scanning device that provides multiple head high-speed rotary scanning devices for reading an image on a phosphor screen and methods for its use. In a first embodiment of the present invention, Figures 13A and 13B show schematic top plan view of preferred aspects of a three-head rotary scanning device 220 according to the present invention as positioned over the surface of phosphor screen 210 and 210a respectively. Rotary scanning device 220 comprises three radially extending optical trains 212 oriented at 120.degree. to one another on its underside. (The positions of optical trains 212 are shown schematically in Figures 13A and 13B, and the details of optical trains 212a, 212b and 212c are better seen in Figures 15 through 16C). In a preferred manner of operation, scanning device 220 is rotated about its center 213 in direction R as phosphor screen 210 is moved in direction Y. Rotation of scanning device 220 about center 213 can be accomplished by any conventional high speed motor and drive system that produces a constant speed of rotation of scanning device 220. Alternatively, the speed of rotation of the scanning device can be measured and the data acquisition system can be synchronized to compensate for any minor variations in rotation speed. Translation of phosphor screen 210 in direction Y can be accomplished by attaching phosphor screen 210 to a motorized transport mechanism, such as a series of rollers and guides, or to a translation stage.

Each of the three optical trains 212 comprise a single scanning head (either 222, 224, or 226) which is disposed at a location at or near the outer perimeter 215 of scanning device 220, as shown. As will be explained, each individual optical train 212 and its associated scanning head, (being either scanning head 222, 224 or 226), operates to direct a focussed beam of incident laser light towards phosphor screen 210 and to receive response radiation emitted by phosphor screen 210. Using any one of a number of optical trains (such as optical trains 212a, 212b, 212c, 212d or 212e as will be described), response radiation received by the scanning head is separated from the incident laser light and is directed towards a centrally-located photomultiplier tube 240 for gathering image data, as will be explained.

In the embodiments shown in Figures 15 through 16E, each optical train preferably comprises its own laser source 230 such that each scanning head 222, 224 and 226 has its own dedicated laser. By activating each of the three lasers in sequence, each of scanning heads 222, 224 and 226 will sequentially direct laser light onto the surface of phosphor screen 210 while collecting response radiation emitted from phosphor screen 210. By activating each scanning head in sequence, such that only one scanning head is active at a time, or by providing mechanical shielding such that the laser beam in each scanning head reaches the phosphor screen one at a time in sequence, imaging data will be collected from only one scanning head at a time, thereby allowing a single photomultiplier tube to be used for data collection from each of the three optical trains, while preventing stray laser light from adding noise to the collected data signal. Although the present invention operates with one central photomultiplier tube or photodiode, as explained, the present invention also encompasses embodiments having a dedicated photomultiplier tube or photodiode used for each optical train.

In the three head design shown in Figures 13A to 16C, 17 and 24 to 26, each scanning head 222, 224 and 226 will sequentially pass over the surface of phosphor screen 210 in an arcuate path. By advancing the phosphor screen relative to the rotating scanning device, a curved raster scan is generated, which can later be converted from polar coordinates into Cartesian coordinates.

The ratio of optical radius r, (shown in Figure 13A as the distance from center 213 of scanning device 220 to the focal point of the laser beam under scanning head 222), to one-half the width of the phosphor screen is preferably selected such that the focused laser beam under each scanning head (22, 224 or 226) passes completely across the entire

width of phosphor screen 210 one after another, before a subsequent scanning head passes over the phosphor screen. In a preferred aspect, scanning heads 222, 224 and 226 are operated in sequence, such that only one scanning head is actively scanning across the phosphor screen at a time. For example, the laser in scanning head 222's optical train is turned on during the interval of time during which scanning head 222 moves across the phosphor screen from its position as shown in Figure 15A to the position presently occupied by scanning head 226 in Figure 15A. During the interval of time in which scanning head 222 moves across the surface of screen 210, the laser in each of scanning head 224 and 226's optical train will turned off. After scanning head 222 reaches the position presently occupied by scanning head 226, scanning head 222's laser will be turned off and scanning head 224's laser will be turned on.

Alternatively, the lasers in all three optical trains can be continuously operating, with mechanical shielding 211 (positioned between phosphor screen 210 and scanner 220 as shown in Figure 13A), ensuring that the laser beam in each scanning head reaches the phosphor screen one at a time in sequence. Specifically, mechanical shielding can be provided such that the laser beam from any scanning head only reaches screen 210 when the scanning head is passing between the positions occupied by scanning heads 222 and 226 in Figure 13A. Accordingly, as scanning head 222 moves across screen 210 (to the position presently occupied by scanning head 226), the laser beams emitted from scanning heads 224 and 226 will be blocked from reaching screen 210.

Each of the various scanning heads 222, 224 and 226 will preferably have the same optical radius. Specifically, the optical radius r between center 213 to the focal point of the laser beam under scanning head 222 will equal the optical radius between center 213 and the focal points of laser beams under scanning heads 224 and 226.

Optionally, the ratio of the optical radius relative to the phosphor screen width can also be selected such that a very short time gap occurs between the data collection of each subsequent scanning head. Such a short time gap facilitates image data processing as it makes it easier to distinguish between data collected by each of the various scanning heads 222, 224 or 226 and provides time for initialization of the data acquisition system.

As is shown in Figures 13A and 13B, scanning device 220 may comprise a disc, however, as is shown in Figure 24, the rotatable frame of the scanning device may instead comprise a Y-shaped frame 2120 having three radially extending arms connected together at the center of the frame.

In a second embodiment, the present invention encompasses a rotating scanning head positioned with a phosphor screen wrapped partially therearound as is shown in Figures 21 to 23, employing the optical trains as shown in Figures 16D and 16E. As is seen in Figures 21 and 22, phosphor screen 210 is oriented perpendicular to scanning device 220, with phosphor screen 210 wrapped partially around scanning device 220. As seen in Figure 22, scanning device 220 rotates in direction R with screen 210 advanced in direction Z, being perpendicular to the plane of rotation of scanning device 220. It is to be understood that such relative motion can alternatively be achieved by holding curved phosphor screen 220 at a fixed position and moving scanning device 220 in the Z direction, rotating scanning device 220 at a fixed Z location and moving phosphor screen 220 in the Z direction, or some combination thereof.

As can be seen in Figure 21, when using a three head scanner, phosphor screen 210 is preferably wrapped to extend 2120 degrees around scanning device 220, such that it spans the arcuate distance between successive scanning heads 222 and 226 as shown. Similarly, when instead using a two head scanner having optical trains spaced 180.degree. apart, phosphor screen 210 is preferably wrapped to extend 180.degree. around scanning device; and similarly, when using a four head scanner, phosphor screen 210 is preferably wrapped to extend 90.degree. around scanning device to ensure that only one scanning head is passing over the surface of the phosphor screen at a time.

Using this arrangement, (as illustrated for a three head scanner in Figure 21, scanning head 226 will just complete its scan across phosphor screen 210 as scanning head 222 moves into position to scan across phosphor screen 210. An advantage of this embodiment can be seen in Figure 23 which shows successive scan lines 2160, 2161 and 2162 taken across screen 210 by sequential scanning heads 222, 224 and 226 respectively. As can be seen, scan lines 2160, 2161 and 2162 taken across phosphor screen 210 are quite straight, being deflected by the amount of movement in the Z direction between successive scanning heads 222, 224 and 226 moving across the phosphor screen. (The actual separation distance between successive scan lines 2160, 2161 and 2162 has been exaggerated for illustration purposes).

As can be seen in Figure 21, should scanning device 220 be dimensioned such that screen 210 does not span all of the distance between successive scan heads, (for example, should screen 210 reach only between points 2110 and 2111), a gap time will be created between successive scans during the interval of time in which no scanning head is passing

over the phosphor screen, (in particular, during the interval of time a scanning head is passing from points 2111 to 2112).

The Preferred Optical Trains

The optical trains shown in Figures 15 to 16C are preferably for use with the embodiment of the present invention shown in Figures 13A to 14, 17 and 24 to 26. and the optical trains shown in Figures 16D and 16E are preferably for use with the embodiment of the present invention shown in Figures 21 to 23, as will be explained.

Referring to the first embodiment, Figure 15 shows a sectional schematic view of a first optical train comprising a laser 230, dichroic mirror 232, reflecting mirror 234, focussing/collimating lens 236, steering mirror 238, and photomultiplier tube 240. In accordance with this embodiment of the invention, laser 230 emits a collimated beam 231 of laser light which is reflected by dichroic mirror 232 towards reflecting mirror 234 and is further reflected downwardly through lens 236 which focuses beam 231 on phosphor screen 210. A response radiation 233 emitted by phosphor screen 210 will travel upwardly through lens 236 which collimates beam 233 and is then reflected by reflecting mirror 234 along with the same optical path as beam 231. When beam 233 reaches dichroic mirror 232, it will pass therethrough eventually reaching steering mirror 238 which reflects beam 233 into photomultiplier tube 240. Optionally, a second focussing lens 237 can be positioned between dichroic mirror 232 and steering mirror 238. The output of photomultiplier tube 240 over time will correspond to the emitted intensity of emissions along an arcuate scan line across phosphor screen 210. For comparison, Figure 16A illustrates a schematic of the optical train 212a layout as seen in Figure 15.

Scanning head 226 comprises those components located at the radially outward end of the optical train. In this embodiment, scanning head 226 comprises reflecting mirror 234 and focussing lens 236. An advantage of this embodiment is that laser 230 and dichroic mirror 232 can be mounted at an inward location proximal the center of the scanning device. Accordingly, a minimal number of system components are disposed at scanning head 226, and thus, the torque required for rotating scanning device 220 at high-speeds is reduced.

Alternative preferred designs for the optical train are possible. For example, Figure 16B shows optical train 212b comprising laser 230 emitting beam 231 radially outward to reflecting mirror 234 which reflects beam 231 through dichroic mirror 232

and focussing lens 236 towards phosphor screen 210. Response radiation emitted by phosphor screen 210 as beam 233 will be reflected by dichroic mirror 232 radially inwardly to steering mirror 238 which in turn reflects beam 233 to photomultiplier tube 240. In this embodiment, scanning head 226 comprises reflecting mirror 234, dichroic mirror 232 and focussing lens 236.

In another preferred aspect, optical train 212c, (shown in Figure 16C), comprises laser 230 which emits beam 231 directly downwardly onto phosphor screen 210. Beam 233 will be reflected by dichroic mirror 232 towards steering mirror 238 which in turn reflects beam 233 into photomultiplier tube 240. In this embodiment, scanning head 226 comprises laser 230, dichroic mirror 232 and focusing lens 236. An advantage of this embodiment of the optical train is that a reflecting mirror, (such as mirror 234)., is not required.

Optionally, in any of the above preferred aspects of the optical train, a filter 241, which may comprise a red light blocking filter, may be included, and is preferably positioned between steering mirror 238 and photomultiplier tube 240, as shown in Figures 16A to 16E. Filter 241 will preferably permit blue wavelength emitted response radiation beam 233 to pass therethrough, yet prohibit the passage of reflected or scattered red wavelength incident laser therethrough. Optionally as well, a collimating lens 235 can be positioned adjacent laser 230 for producing a collimated laser beam, as shown in Figures 16A to 16E.

An important advantage common to all the above described optical trains 212a, 212b, 212c, 212d and 212e is the absence of moving parts since the relative movement of each of the scanning heads 222, 224 and 226 over phosphor screen 210 is accomplished by rotating scanning device 220 about center 213 and moving phosphor screen 210, (or moving scanning device 220), in direction Y by a transport mechanism. Accordingly, the present invention avoids problems of accurately controlling the position of a scanning head which is constantly changing speed while moving back and forth in one or more directions.

In the alternative embodiment shown in Figures 21 to 23, optical trains 212d or 212e (Figures 16D and 16E) are used. In both optical trains 212d and 212e, the laser beam 231 is directed radially outwardly through focussing lens 236 to phosphor screen 210. In contrast, in optical trains 212a to 212b, (Figures 16A to 16B), a reflecting mirror

234, is used to reflect the laser beam 231 downwardly 290.degree. toward phosphor screen 210.

Using any of the various above described embodiments of the optical train, the laser light beam 231 emitted from laser 230 may preferably have a wavelength of about 635 to 680 nM and a power in the range of 0 to 30 mW. Response radiation beam 233 will typically have a wavelength centered at about 390 nM. Focussing/collimating lens 236 may comprise a 25 to 215 mm diameter lens with a focal length of 4 to 10 mm which will focus the collimated beam 231 of laser light into a beam width of about 25 to 250 microns, and most preferably 30 to 80 microns on the surface of phosphor screen 210. Minimizing the diameter of the incident laser light beam upon the phosphor screen will minimize destructive pre-reading of the image data caused by forward overlap of the focused beam and reflected and scattered laser light. It is to be understood that the foregoing wavelengths, powers and sizes are merely exemplary and that other wavelengths, powers and sizes may also be used.

The Use of Different Numbers of Equally Spaced Apart Scanning Heads

The present invention encompasses designs with two, three, four or more scanning heads. The advantages of each of these various designs will be described below.

Using a laser beam excitation system to read an image trapped in a phosphor screen is a "one-time" operation since the actual reading of the stored image by the laser beam will operate to release the image. It is therefore not possible to scan the same pixel of the phosphor screen again and again.

Figure 17 is an geometric representation of successive scan lines taken by the rotating scanning device 220 of Figure 13A (not shown) above phosphor screen 210 as screen 210 is incrementally moved in the Y direction. (The actual separation distances between scan lines 2150 and 2152 are exaggerated in Figure 17 for illustration purposes.) As the scanning device is rotated, a first arcuate scan line 2150 will be taken by a first scanning head passing across the surface of phosphor screen 210 from edge 2103 to edge 2105. Coincident to the first scanning head reaching edge 2105, phosphor screen 210 will have advanced in direction Y by distance D1. Accordingly, a second scan line 2152 will then be taken across phosphor screen 210 by a second scanning head passing from edge 2103 to 2105.

As can be seen, distance Dr. is the distance separating scan lines 2150 and 2152 at center location 2104. Distance D2 is the distance separating scan lines 2150 and 2152 at edge 2105, (and also edge 2103), as shown. (In particular, distance D2 is measured as the perpendicular distance between lines tangential to scan lines 2150 and 2152 at edges 2105 and 2103.) As can be seen, distance D2 is smaller than distance Dr. since the separation spacing between lines 2150 and 2152 will progressively narrow towards the edges of the phosphor screen.

To avoid destructive reading caused by scanning the same pixel in the phosphor screen more than once, it is therefore important that the separation distance D2 between successive scan lines 2150 and 2152 does not become too small, and in particular does not become much smaller than the focussed laser beam spot diameter. Should the separation distance D2 become somewhat smaller than the focussed laser beam spot diameter, successive scanning heads will tend to pass over the same pixels at the edges of the phosphor screen, resulting in destructive reading. Accordingly, it is therefore desirable to maintain a sufficient distance D2, which will be defined in part by the diameter of the focussed laser beam. As can be appreciated, the straightness of scan lines 2150 and 2152 is determined by the ratio of the scanning device optical diameter to phosphor screen width, with straighter scan lines occurring as the ratio of the scanning device optical diameter to phosphor screen width is increased. The larger the spacing of D2 becomes at the edges of the phosphor screen, the less potential for destructive reading at the edges of the phosphor screen.

Figure 18A shows a two head scanning device 250a having scanning heads 252 and 254. Scanning device 250a is dimensioned such that the separation distance between scanning heads 252 and 254 is equal to the width of phosphor screen 210. As scanning device 250a is rotated in direction R, each of scanning heads 252 and 254 will sequentially trace an arcuate semi-circular path across the surface of phosphor screen 210 from edge 2108 to edge 2106. Scanning heads 252 and 254 are always positioned over the phosphor screen, however, scanning heads 252 and 254 are activated one at a time such that after scanning head 252 has scanned across the phosphor screen from side 2108 to 2106, (and is then turned off), scanning head 254 will have moved into the position currently occupied by scanning head 252 such that scanning head 254 can be turned on to similarly scan across the phosphor screen from edge 2108 to 2106.

A major limitation of the system of Figure 18A is the fact that the reading of the image stored in screen 210 will result in destructive reading of image data proximal the edges of the screen 210 since scanning heads 252 and 254 will tend to pass over the same pixels one after another at screen edges 2106 and 2108. Specifically, should an attempt be made to acquire a pixel by pixel scan of the phosphor screen using the system as dimensioned in Figure 18A, it is difficult to generate meaningful data toward screen edges 2106 and 2108, due to the fact that data sampling will essentially comprise oversampling the same pixels with each scan, thereby attempting to re-read pixels from which the stored image has already been released.

As was stated, it would be desirable to have the sequential scan lines passing across the surface of the phosphor screen being as straight as possible, such that adequate separation is maintained between these scan lines at the edges of the screen, (such that individual pixels are not sampled more than once).

In the embodiment of the present invention shown in Figure 18B, the two head scanning device is instead dimensioned with a larger diameter to screen width ratio than as illustrated in Figure 18A. As such, straighter scan lines, (having greater separation distance therebetween at the edges 2108 and 2106 of phosphor screen 210), will be generated. However, time gaps will occur between the data sampled by the scanning heads, due to the fact that both scanning heads 252 and 254 will be positioned off the surface of the phosphor screen for some time during each revolution of the scanning device. This problem can be addressed by increasing the rotational speed of the scanner, such that screen 210 can still be scanned in a relatively short period of time. An advantage of the two head scanning system is that only two optical trains need to be built, making the device easier to manufacture and reducing the weight of the system.

In an alternate embodiment of the invention as shown in Figure 13A, a three head scanning device is used. The selection of three heads spaced 2120 degrees apart coupled to a single central photodetector as shown has a number of advantages. As will be explained, when the optical radius at 1.1547 times one-half the width W10 of screen 210, 100% read efficiency can be achieved with successive scanning heads moving across the screen one after another with no duty cycle time lost between successive scanning heads. In particular, a first scanning head will just complete its scan across the screen (and begin to move off the surface of the screen), at the same time that a second scanning head will just commence its scan across the screen (and begin to move onto the surface of the

screen). Further advantages of the three head scanning system is that it has a minimal number of separate optical trains, a reasonably small scanning device diameter, at the same time providing sufficiently straight scan path across the surface of the phosphor screen such that sequential scan lines are sufficiently separated at the edges of the phosphor screen such that the diameter of the focussed laser beam does not result in destructive pre-reading.

Figure 19 shows a four head scanning device 260, having four scanning heads 262, 264, 266 and 268 which are equally spaced at 90.degree. to one another. Scanning device 260 is dimensioned to have a diameter greater than the width of screen 210, as shown, such that sufficiently straight scan lines can be taken as scanning head 262 moves to the position presently occupied by scanning head 268. An advantage of the four head scanner of Figure 19 is that the system can be dimensioned with the ratio of scanner diameter to screen width set such that successive scan heads move into position and commence scanning across the screen at the moment in time when the preceding scanning head stops scanning as it passes off the surface of the phosphor screen, as shown.

As can be appreciated, it is possible to add additional numbers of scanning heads. For example, a six head scanning device 270, having six equally spaced apart scanning heads 271, 272, 273, 274, 275, and 276 is shown in Figure 20. By increasing the optical diameter of the rotary scanning device relative to the width of the phosphor screen, the scan lines are progressively straightened. By adding additional numbers of scanning heads, the advantage of avoiding gaps in data collection is achieved.

A number of different preferences, options, embodiment, and features have been given above, and following any one of these may results in an embodiment of this invention that is more presently preferred than a embodiment in which that particular preference is not followed. These preferences, options, embodiment, and features may be generally independent, and additive; and following more than one of these preferences may result in a more presently preferred embodiment than one in which fewer of the preferences are followed. In some embodiments, the ratio of pumping wavelength intensity to erasing wavelength intensity is 50/50, while in others the ratio of pumping to erasure may be 40/60, 60/40, or the like. The present invention may also be adjusted to provide erasing quality from at least 10000:1, 15000:1, 20000:1, 25000:1, 30000:1, 35000:1, 40000:1, and/or 45000:1

While the invention has been described and illustrated with reference to certain particular embodiments thereof, those skilled in the art will appreciate that various adaptations, changes, modifications, substitutions, deletions, or additions of procedures and protocols may be made without departing from the spirit and scope of the invention. Any of the embodiments of the invention may be modified to include any of the features described above or feature incorporated by reference herein. For example, the wavelength sources at specific wavelengths may be combine with other erasure schemes as known in the art. Intermediate bands, triple combinations, or other ways of producing spectra instead of LEDs may also be used. Single sources may be designed to have tailored spectrums which provide both a pumping wavelength and an erase wavelength. The size of the boards may also vary. In on embodiment, it may be 2.5-3 inches wide. LEDs on the boards can also be interspersed, with LEDs of different wavelengths on the same board. Colored wavelengths with at least one broadband source. They may be used in combination in a specified sequence (where one of the sources is broadband such as but not limited to a broadband LED or other silicon device). Some embodiments of the present invention may also direct pump wavelength and erasure wavelength energy to the same screen and that energy may be directed to the same positions on the screen or to different positions of the same screen. In any of the above embodiments, the wavelength sources may direct energy sequentially onto the screen, it may occur simultaneously, or any combination of the two. Although the present application describes the present invention context of phosphor image screens, it should be understood that the present invention may be used with other image screens or other storage devices.

The publications discussed or cited herein are provided solely for their disclosure prior to the filing date of the present application. Nothing herein is to be construed as an admission that the present invention is not entitled to antedate such publication by virtue of prior invention. Further, the dates of publication provided may be different from the actual publication dates which may need to be independently confirmed. All publications mentioned herein are incorporated herein by reference to disclose and describe the structures and/or methods in connection with which the publications are cited.

Expected variations or differences in the results are contemplated in accordance with the objects and practices of the present invention. It is intended, therefore, that the invention be defined by the scope of the claims which follow and that such claims be interpreted as broadly as is reasonable.

WHAT IS CLAIMED IS:

1. A method for erasing an image on a storage device, said method comprising:

exposing the storage device to energy at a pumping wavelength; and

exposing the storage device to energy at an erasing wavelength different from said pumping wavelength.

2. A method for erasing an image on an image storage screen, said method comprising:

exposing the screen to energy at a pumping wavelength, wherein said pumping wavelength is in the visible spectrum; and

exposing the screen to energy at an erasing wavelength different from said pumping wavelength.

3. The method as in claim 2 wherein the screen is exposed to the pumping wavelength before being exposed to the erasing wavelength.

4. The method as in claim 2 comprising simultaneously exposing different areas of the same screen to the pumping wavelength and the erasing wavelength.

5. The method as in claim 2 comprising simultaneously exposing one area on the screen to pumping wavelength and erasing wavelength.

6. The method as in claim 2 comprising exposing the screen to energy at a third wavelength.

7. The method as in claim 2 comprising using a broadband wavelength source to provide at least one of the following: the pumping wavelength, the erasing wavelength, or both the pumping and erasing wavelengths.

8. The method as in claim 2 wherein the pumping wavelength is outside the ultraviolet spectrum.

9. The method as in claim 2 wherein the pumping wavelength is between about 400nm and 640nm.

10. The method as in claim 2 wherein the erasing wavelength is longer than 600nm.

11. The method as in claim 2 comprising using a single energy source having an energy output that is weighted to provide greater energy intensity at both the pumping wavelength and at the erasing wavelength.

12. The method as in claim 2 comprising erasing the screen to a ratio from 50000 counts before erasing to 1 count after erasing.

13. The method as in claim 2, wherein the desired erasing depth may be selected by changing the duration of the exposure of the imaging plate to the pumping and erasing wavelengths.

14. The method as in claim 2 wherein the desired erasing depth may be selected by choosing the relative intensities of the pumping and erasing wavelengths.

15. The method as in claim 2 wherein the desired erasing depth may be selected by choosing the total intensity of the pumping and erasing wavelengths.

16. The method as in claim 2 further comprising using a multiple head device to read the image prior to erasure.

17. The method as in claim 2 further comprising transporting the screen along a path having at least one curved portion, said path moving the screen past a reader and then to an erasing assembly that performs the erasing steps.

18. The method as in claim 2 further comprising transporting the screen along a path in a readout and erase device, said path having at least one curved portion and moves the screen from a top side of the device to an underside of the device.

19. A storage screen erasure device comprising:

a first wavelength source;

a second wavelength source;

wherein said first wavelength is selected to pump signal on the screen to be more easily erased by said second wavelength source and wherein said first wavelength source is in the visible spectrum; and

a controller having logic to activate the sources to erase images from the storage screen.

20. The device of claim 19 wherein the first wavelength source and the second wavelength source comprise a plurality of LEDs.

21. The device of claim 19 wherein the first and second source comprise LEDs on separate boards.

22. The device of claim 19 wherein the first and second source comprise LEDs on the same board.

23. The device of claim 19 wherein said first wavelength is about 460 nm and said second wavelength is at about 640 nm.

24. The device of claim 19 wherein said first wavelength is greater than about 400 nm but less than said second wavelength, wherein said second wavelength is greater than about 600 nm.

25. An integrated device comprising:

a multiple head image screen scanner for extracting an image stored on said image screen;

an image erasure device of claim 19 coupled to said scanner; and

an image screen conveyor systems configure to move said image screen in manner so that the image screen is first read by the scanner and then moves along the feeder to the erasure device.

26. A device comprising:

a broadband wavelength source;

a narrowband wavelength source at a pumping wavelength

wherein said narrowband wavelength source is selected to pump signal on the screen to be more easily erased by said broadband.

27. A method for making a radiography device using an image storage screen, said method comprising:

providing a first wavelength source;

providing a second wavelength source;

wherein said first wavelength is selected to pump signal on the screen to be more easily erased by said second wavelength source;

coupling said first wavelength source and a second wavelength source to housing with a device for reading signals from said screen.

28. The method as in claim 27 comprising providing a screen transfer device that can provide a throughput of X screens of size Y per minute.

29. The method as in claim 27 wherein said first wavelength source and said second wavelength source are at wavelengths outside a wavelength used to read signal from the screen.

30. The method as in claim 27 further comprising providing an optical coupler to direct light from the first wavelength source and the second wavelength source to the same location on the screen.

31. The method as in claim 27 providing a third wavelength source.

32. The method as in claim 27 wherein said first wavelength source and second wavelength source provide an erasure ratio of 50000 to 1.

33. The method as in claim 27 wherein said first wavelength source and second wavelength source comprise a plurality of LEDs.

34. The method as in claim 27 wherein an image erase device is coupled to one end of an image screen reading device.

35. The method as in claim 27 further comprising providing a shield positioned to prevent light from erase device from reaching an image readout area.

36. The method as in claim 27 further comprising providing at least one of the following for the first or second wavelength source: an LED, a laser, a laser diode, or a lamp.

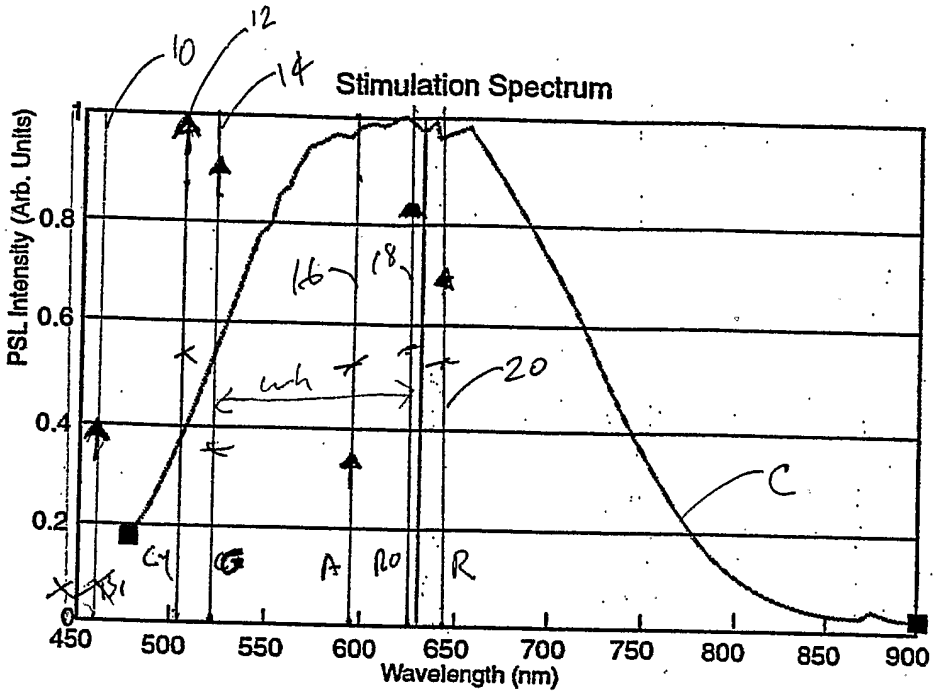

Stimulation Spectrum
PSL Intensity (Arb. Units)
0
0.2
0.4
0.6
0.8
1
450
500
550
600
650
700
750
800
850
900
Wavelength (nm)
10
12
14
16
18
20
C
B
G
A
R

FIG 1

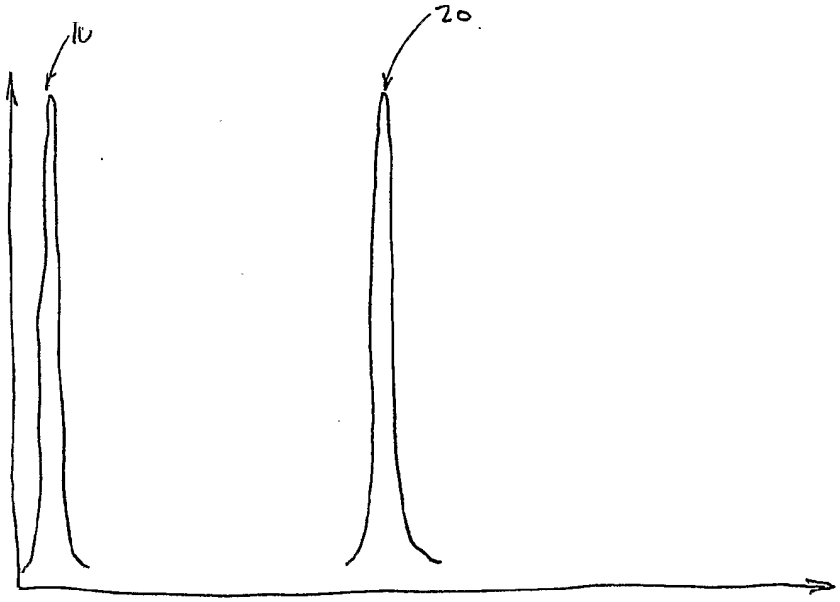


FIG_ 2

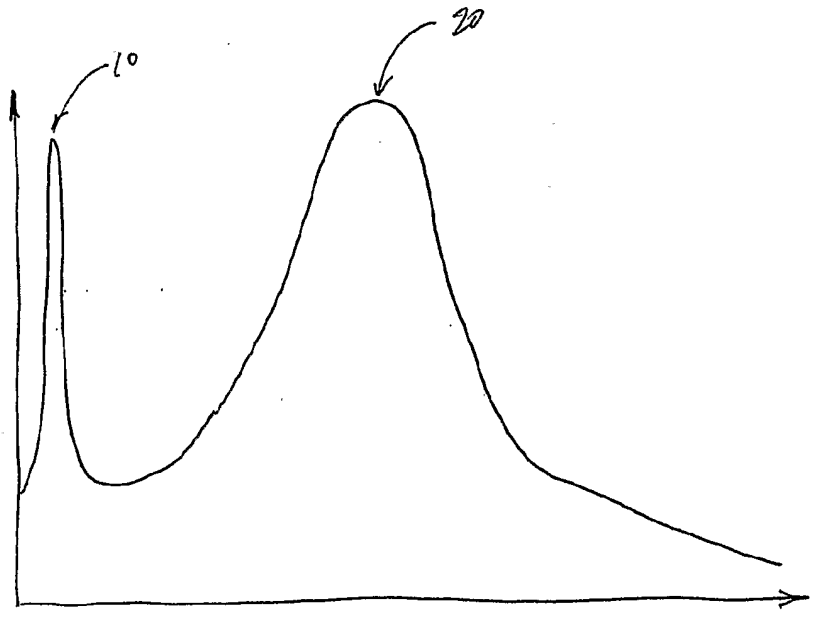


FIG_ 3

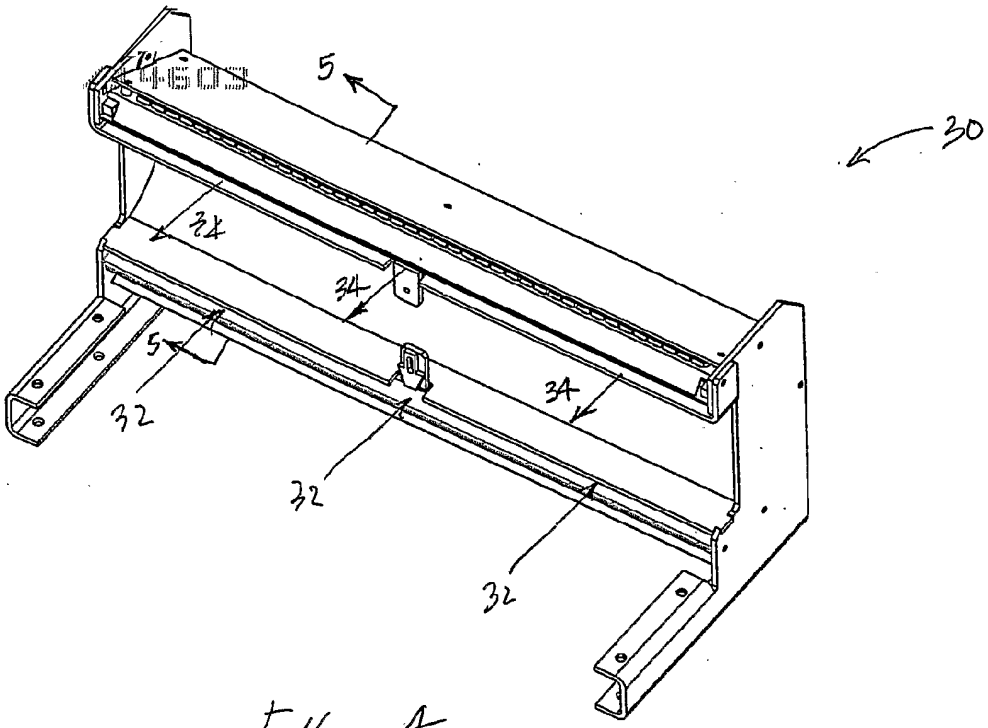


FIG_4

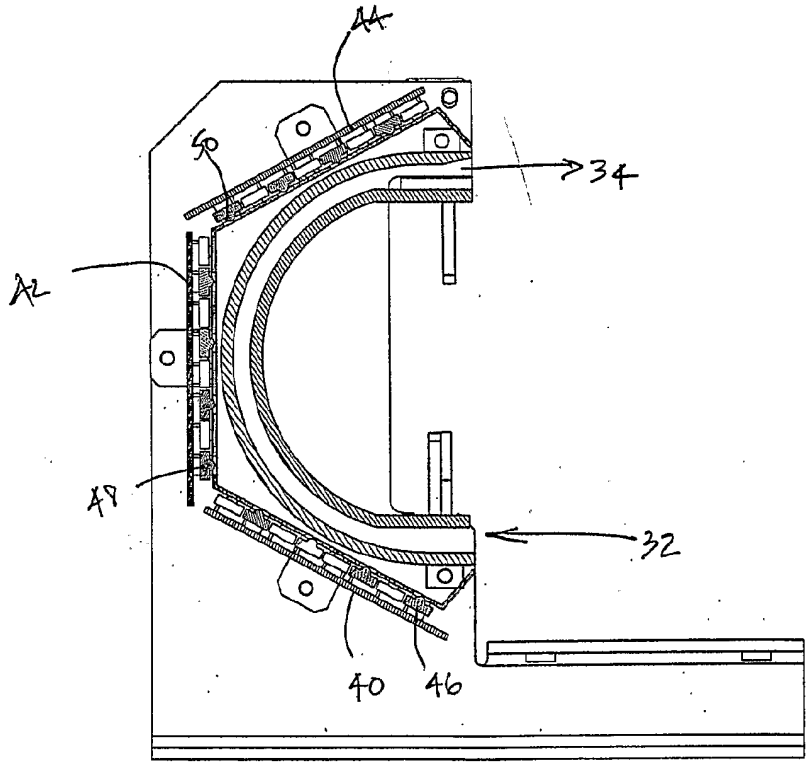


FIG_5

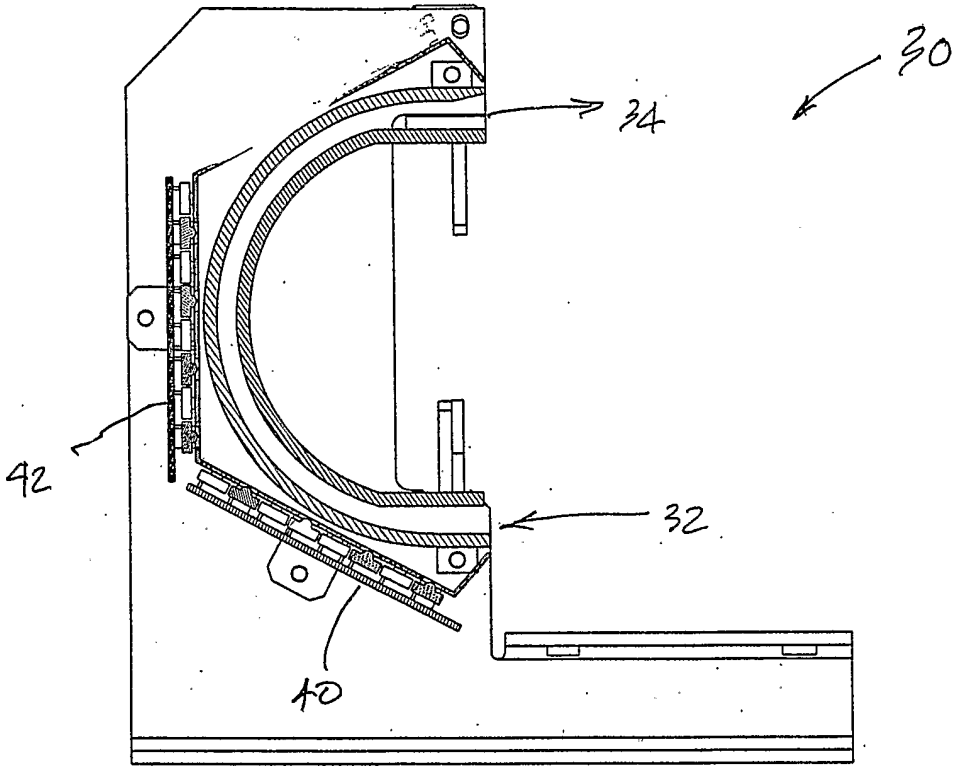


FIG_ 6

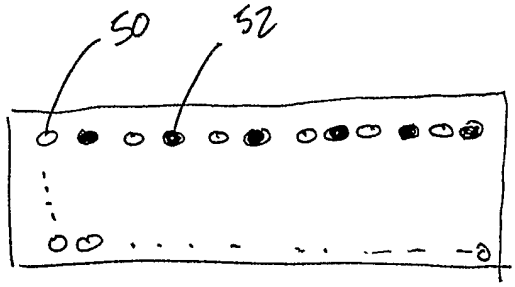


FIG_7

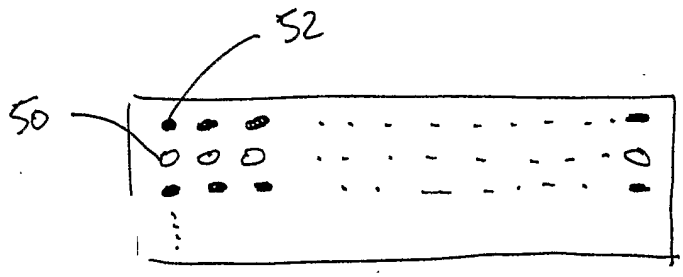
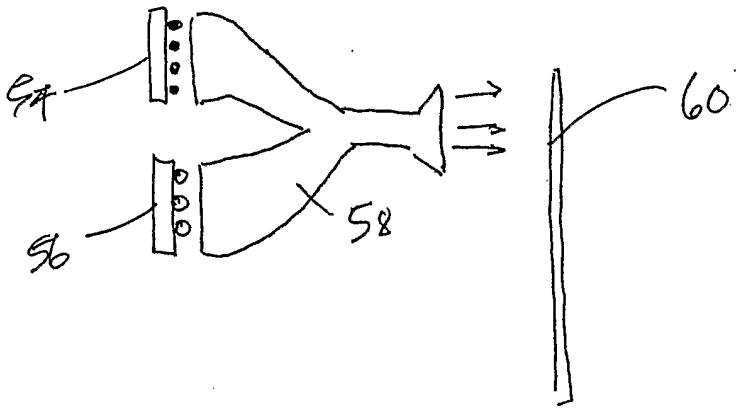


FIG_8



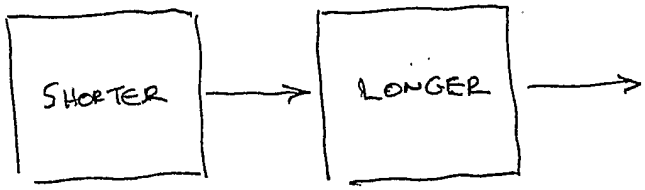


FIG_10

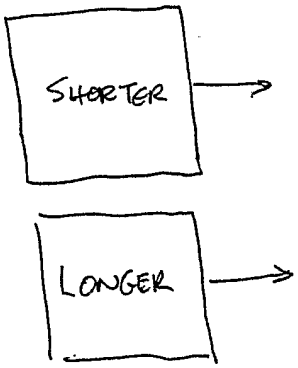


FIG_11

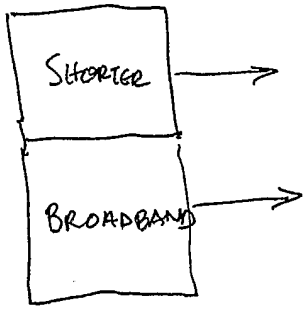


FIG_12

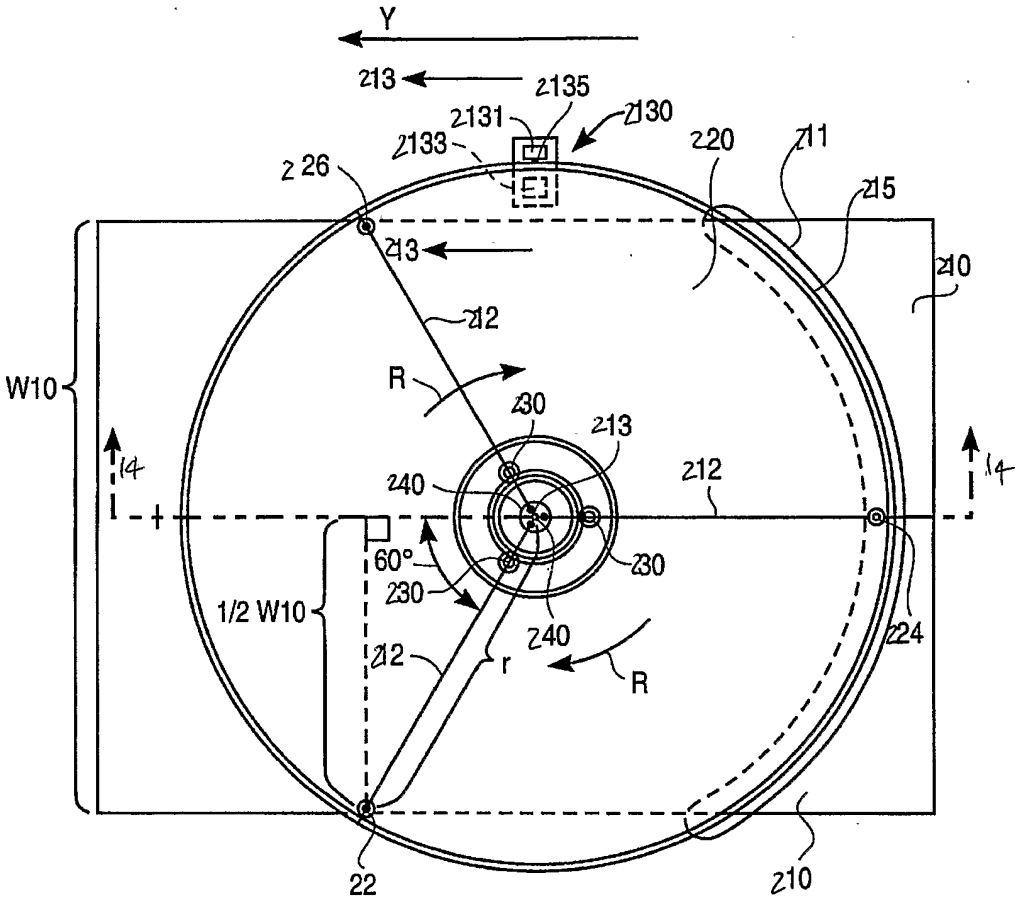

Y
213
2135
2131
2130
2133
220
211
2 26
215
213
210
212
R
W10
230
213
14
240
212
14
60°
230
230
1/2 W10
240
224
212
r
R
22
210

FIG. 13A

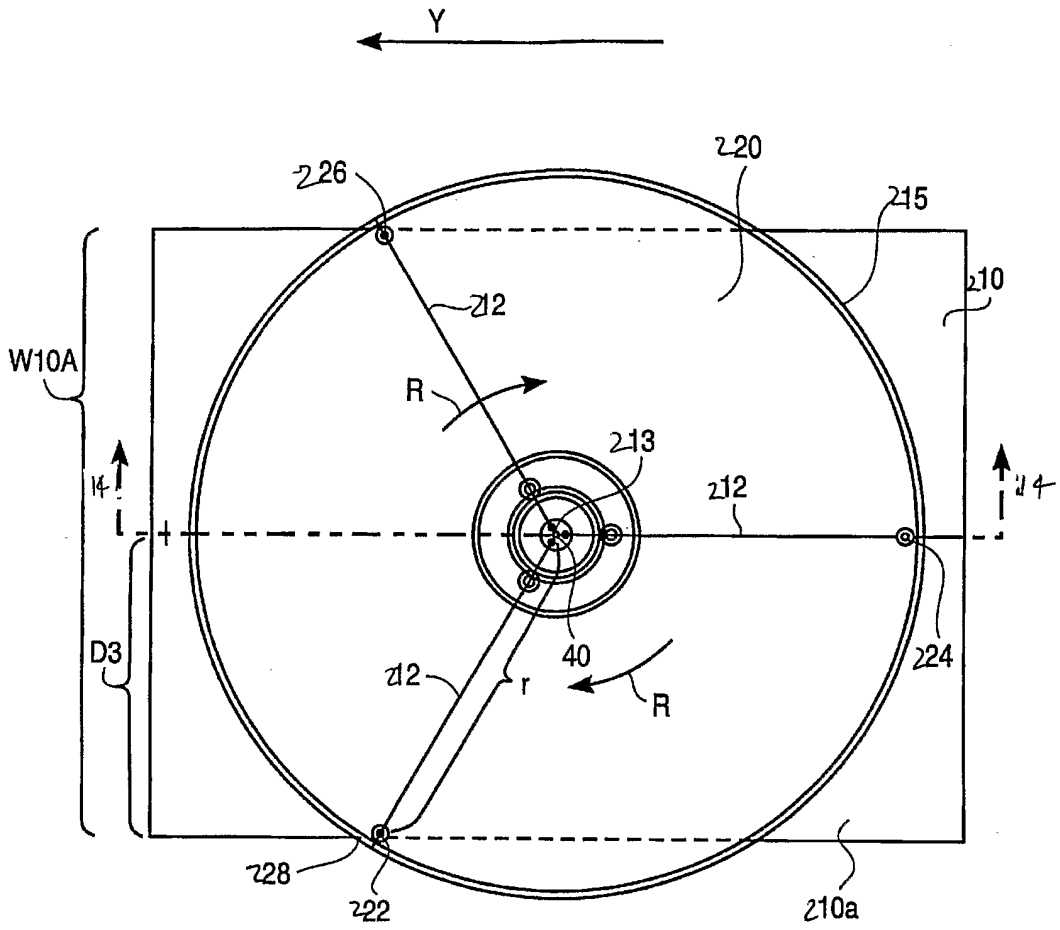

Y
226
220
215
210
212
W10A
R
213
14
212
14
D3
40
212
r
R
224
228
222
210a

FIG. 13B

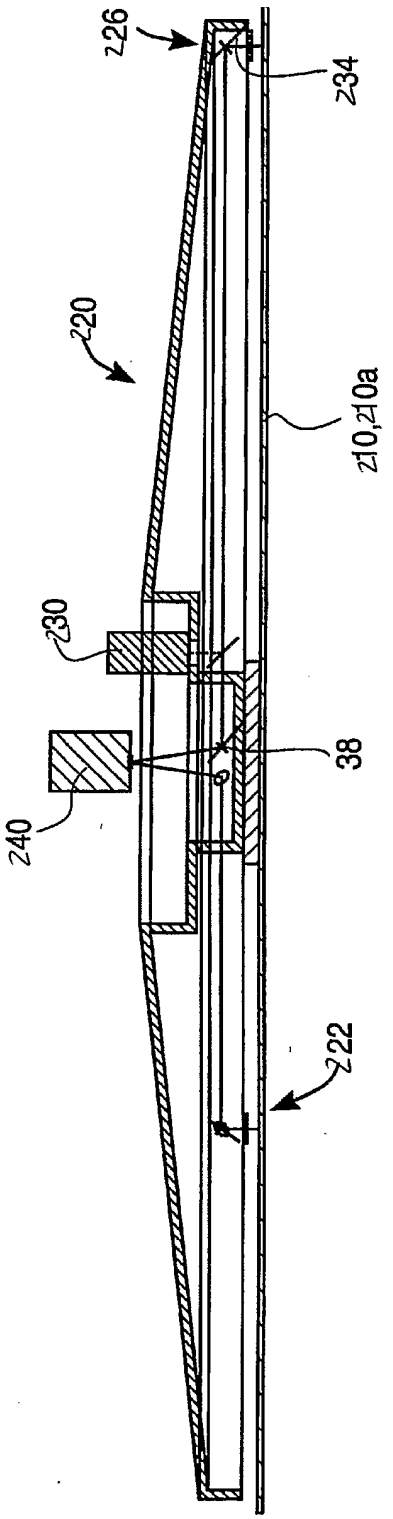


FIG. 14

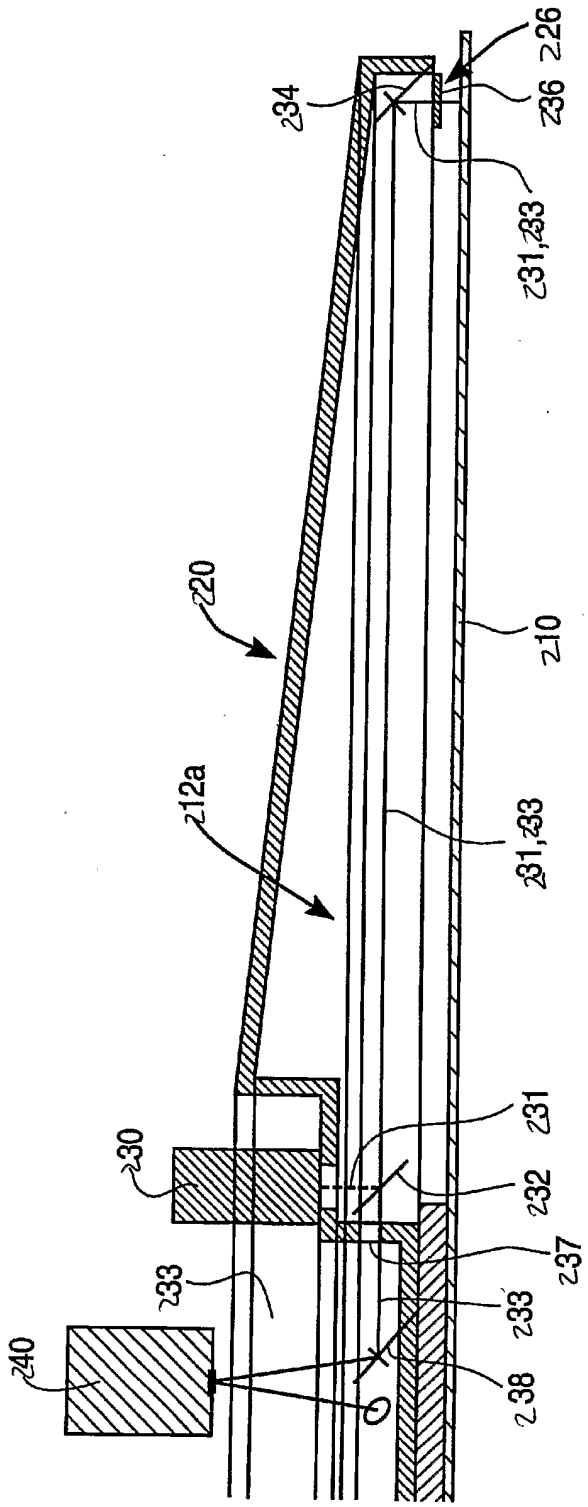

226
234
236
231,233
220
210
212a
231,233
231
230
232
237
233
233
240
238

FIG. 15

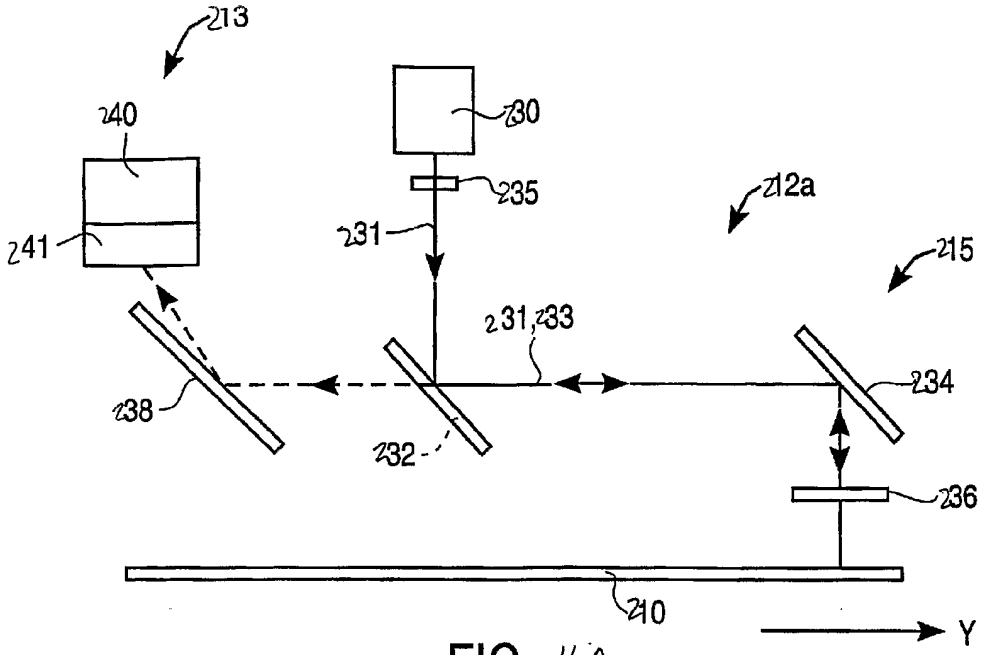


FIG. 16A

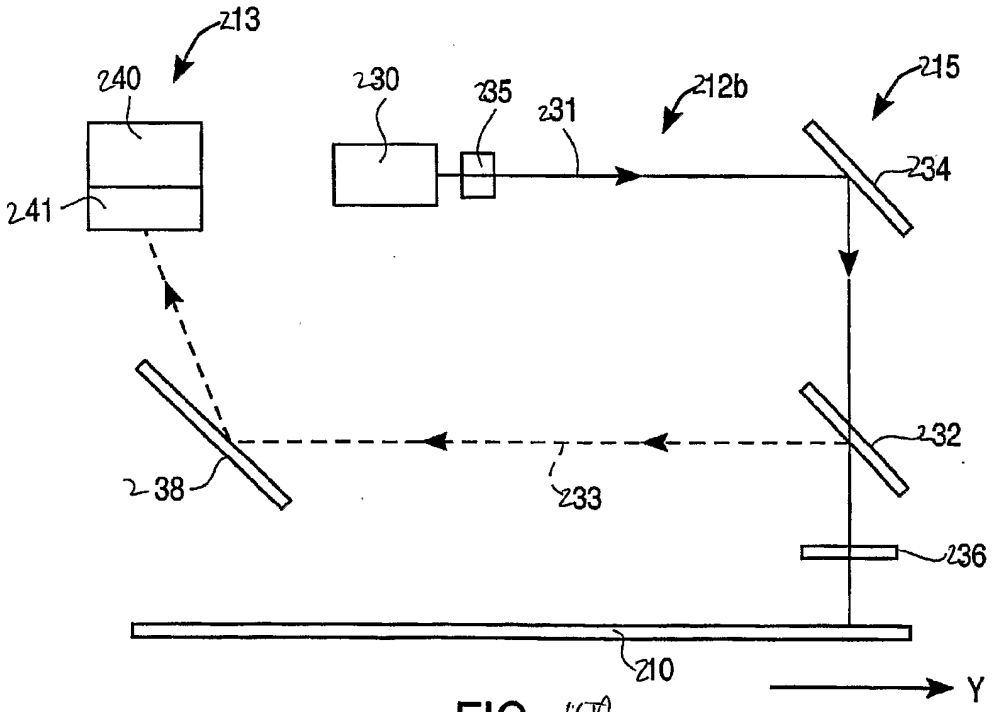


FIG. 16B

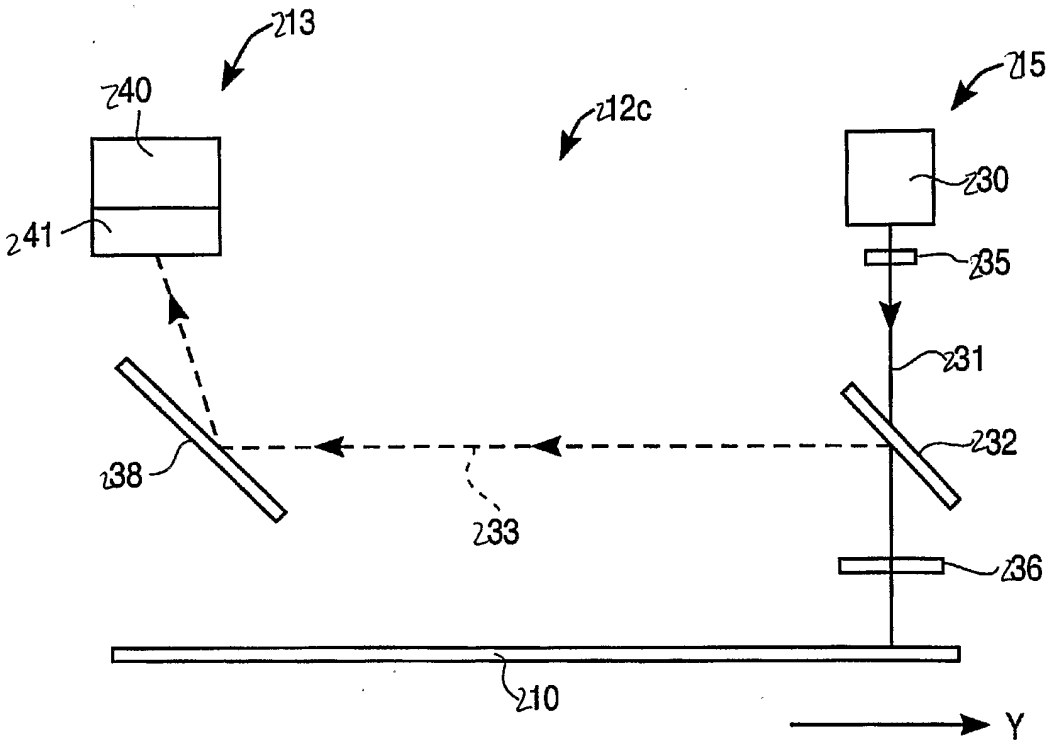


FIG. 16C

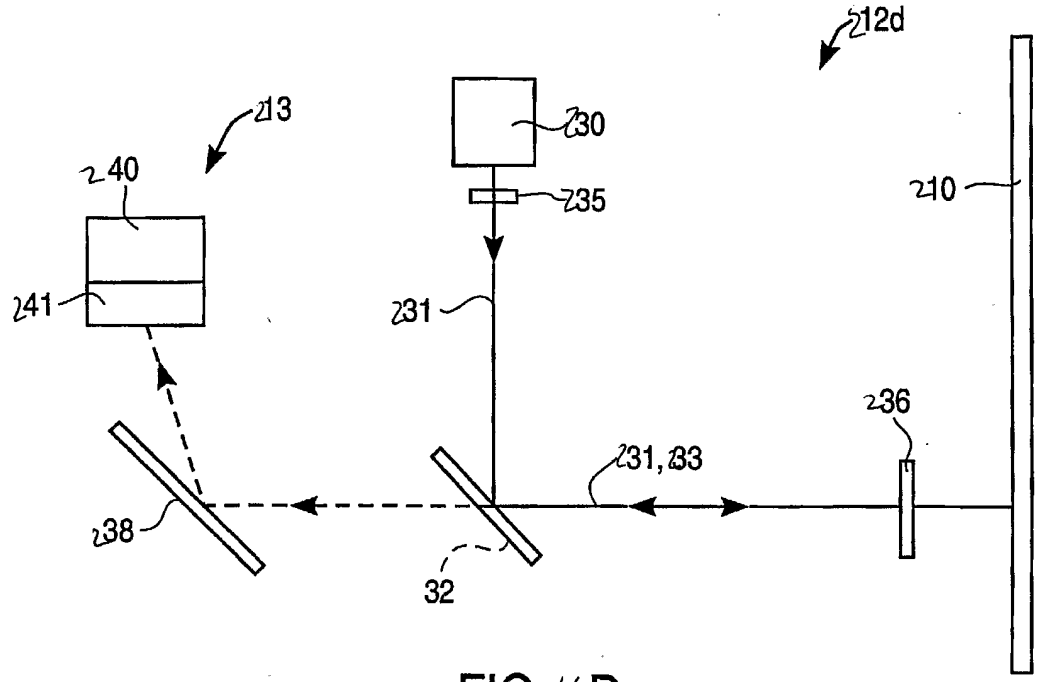


FIG. 16D

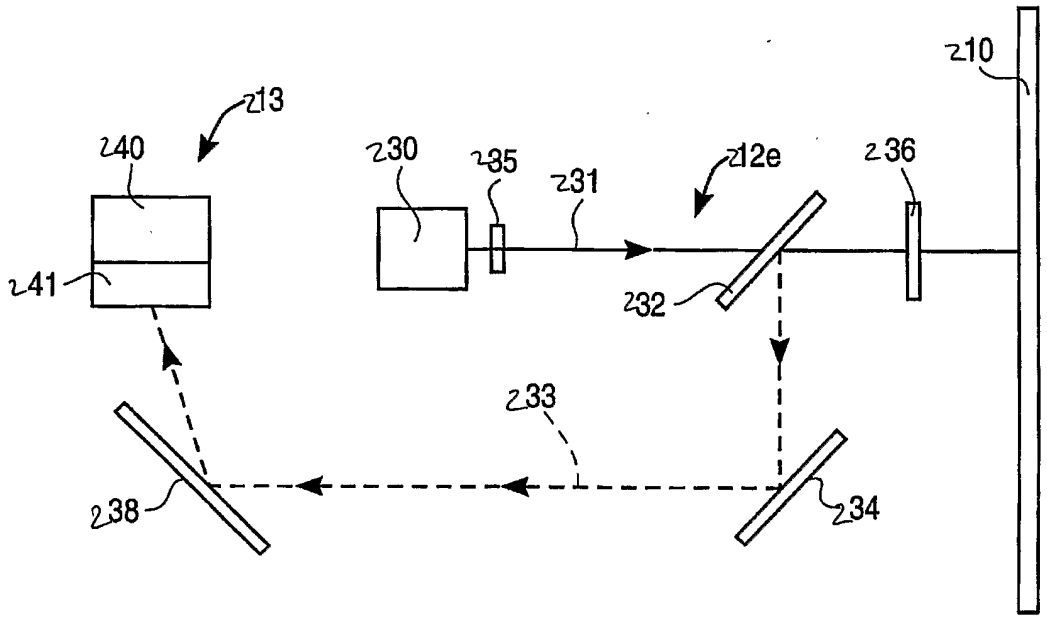


FIG. 16E

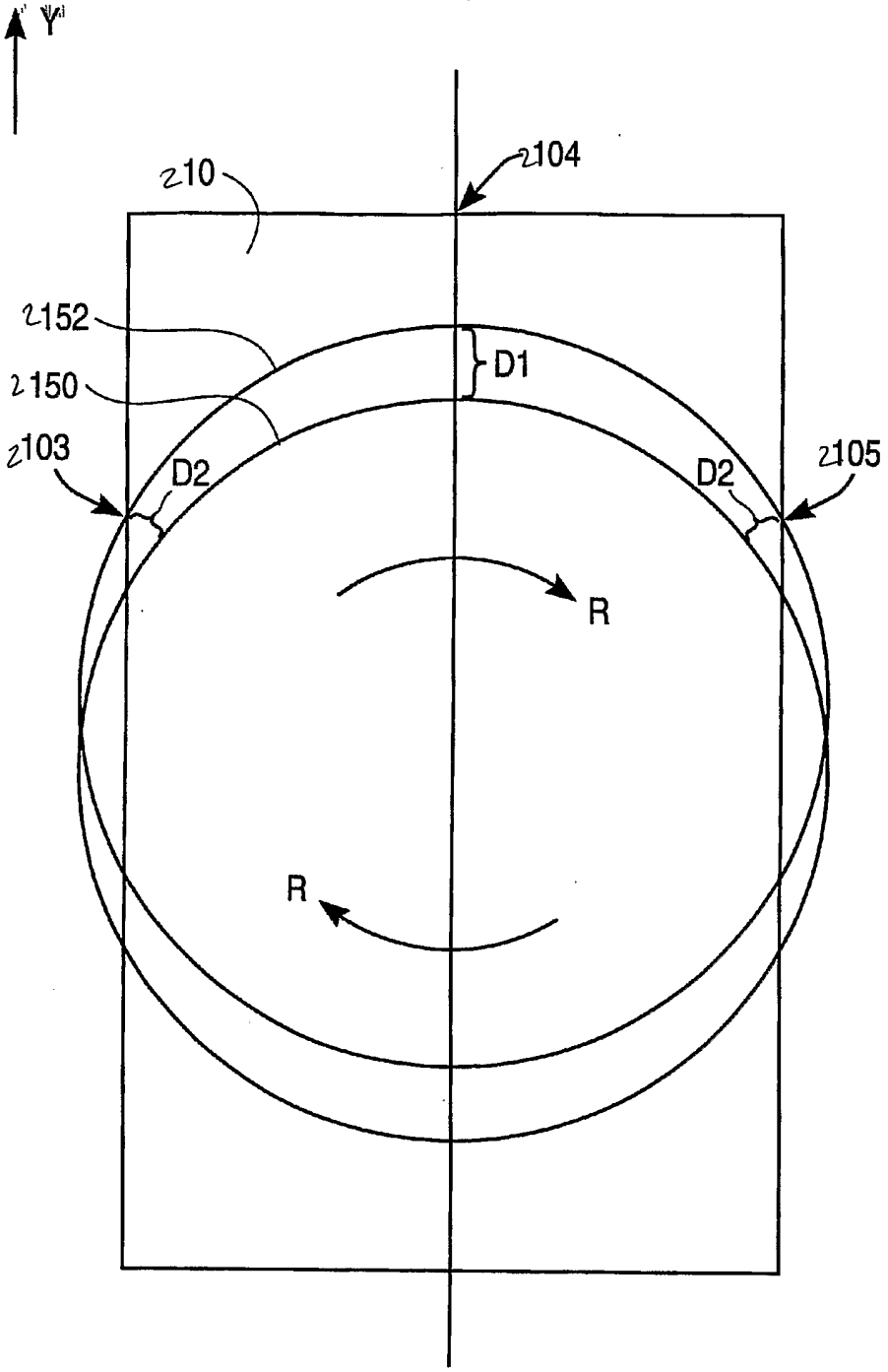


FIG. 17

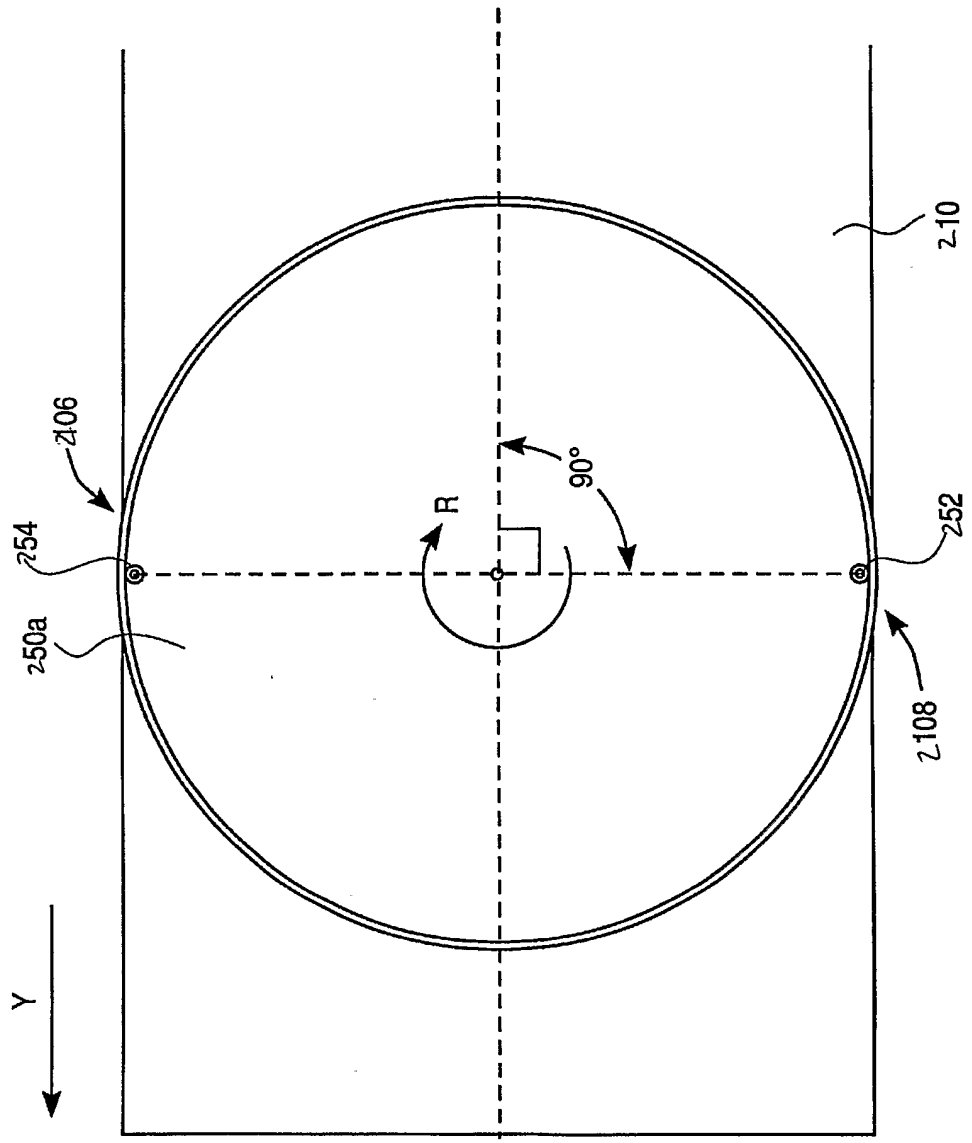


FIG. 18A

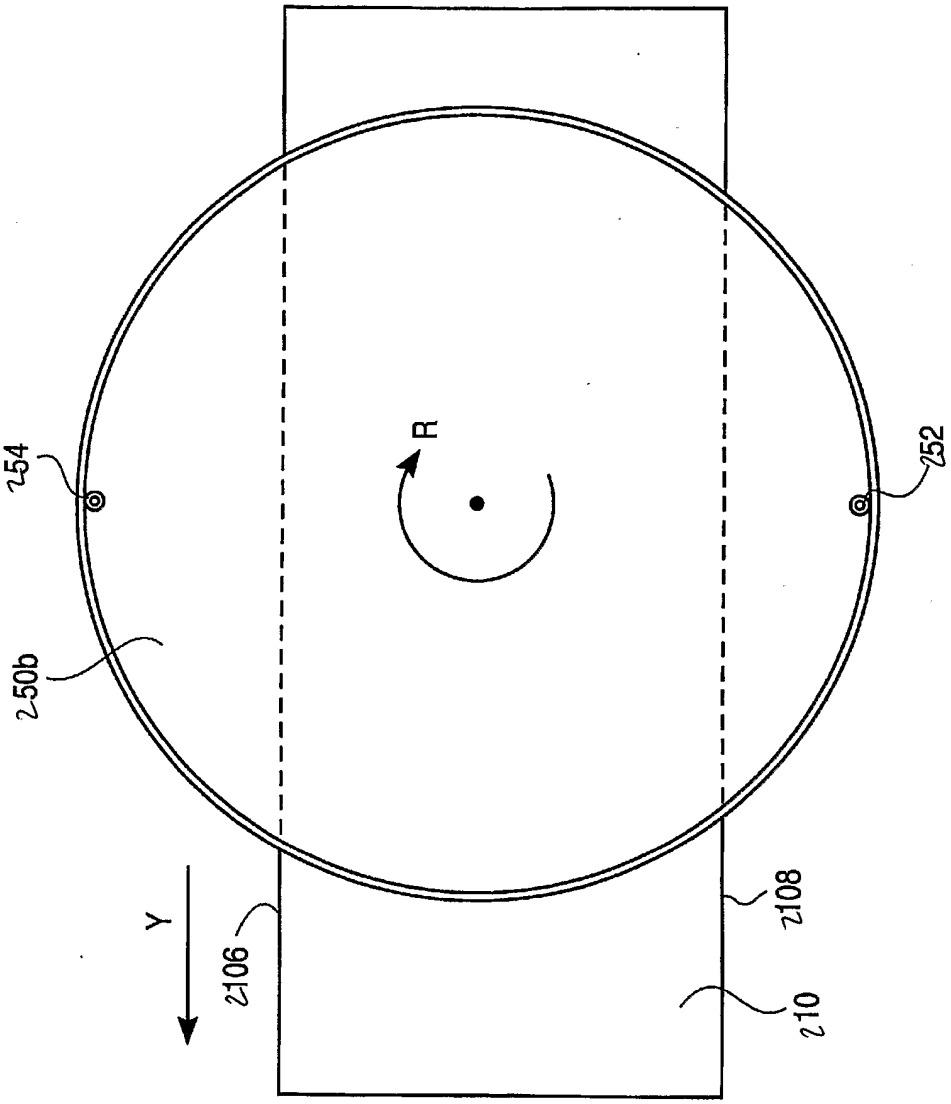


FIG. 18B

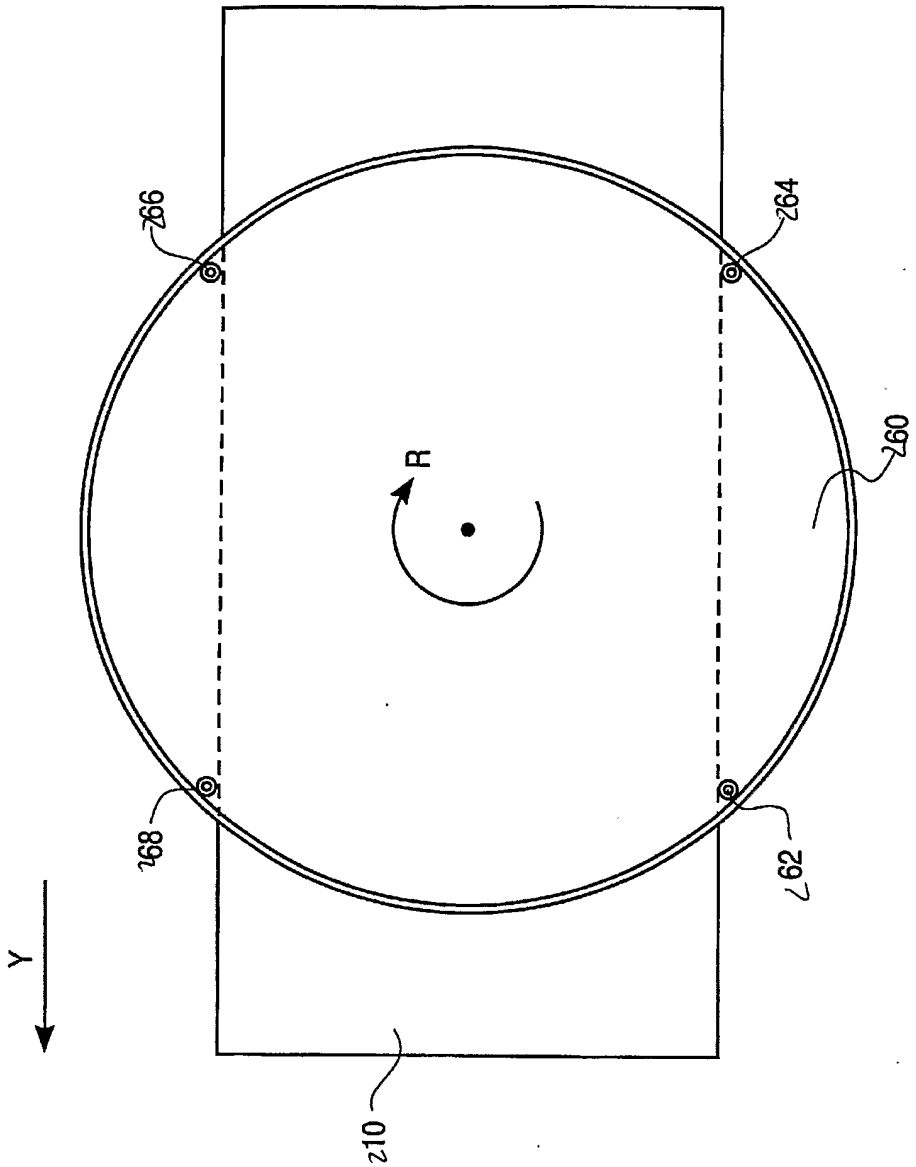


FIG. 19

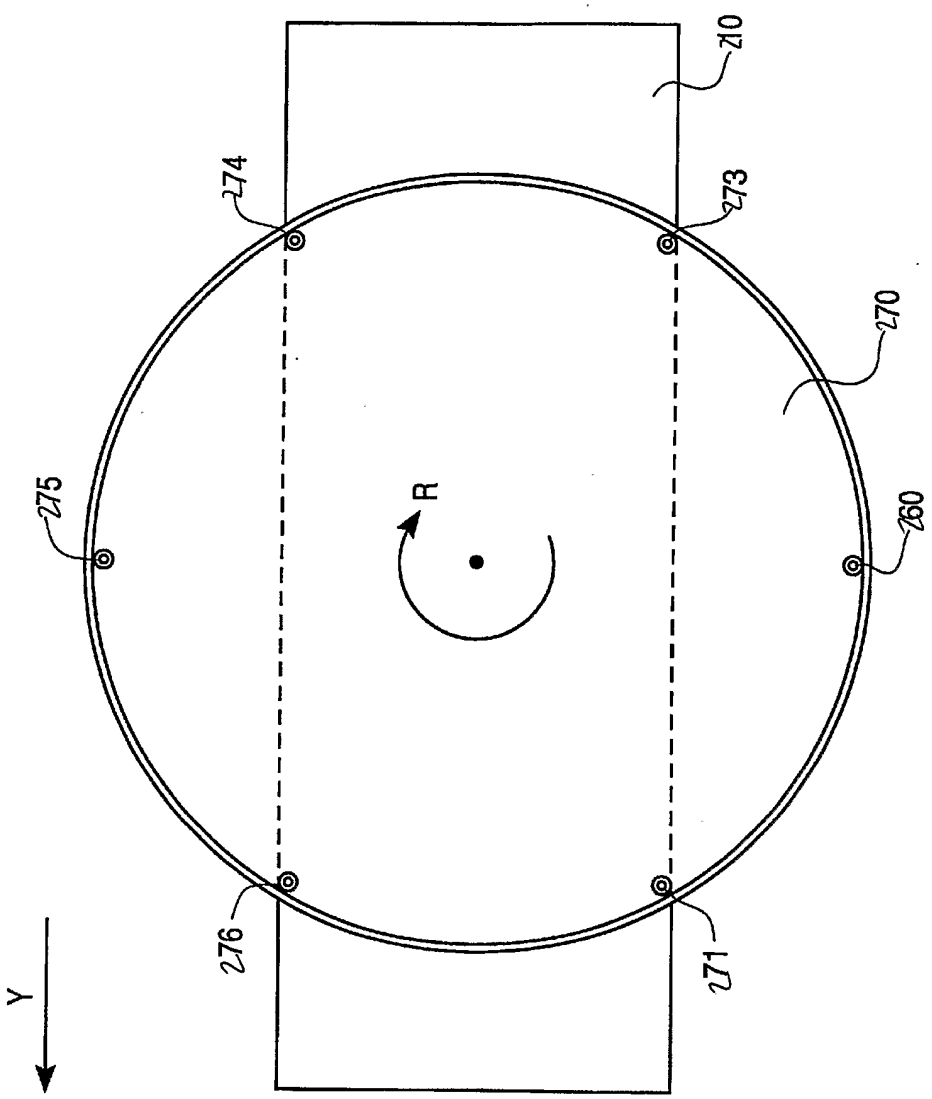


FIG. 20

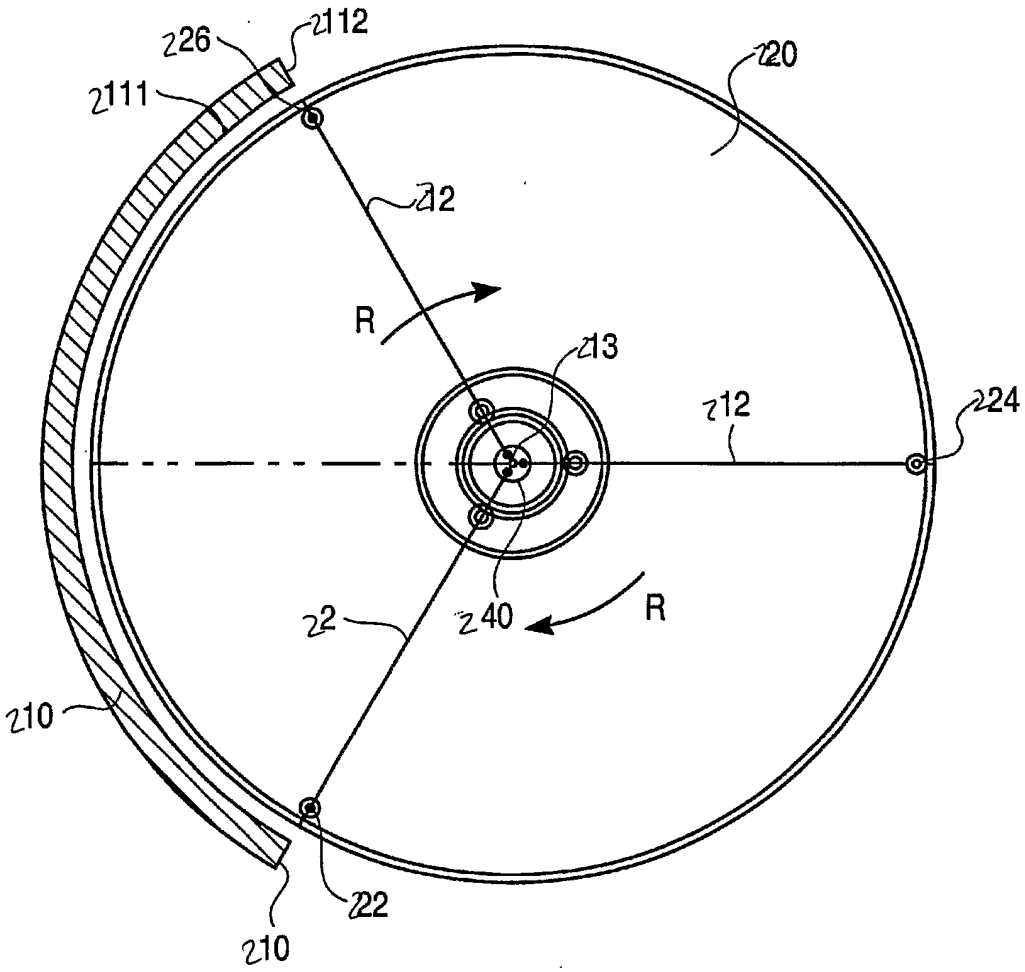


FIG. 21

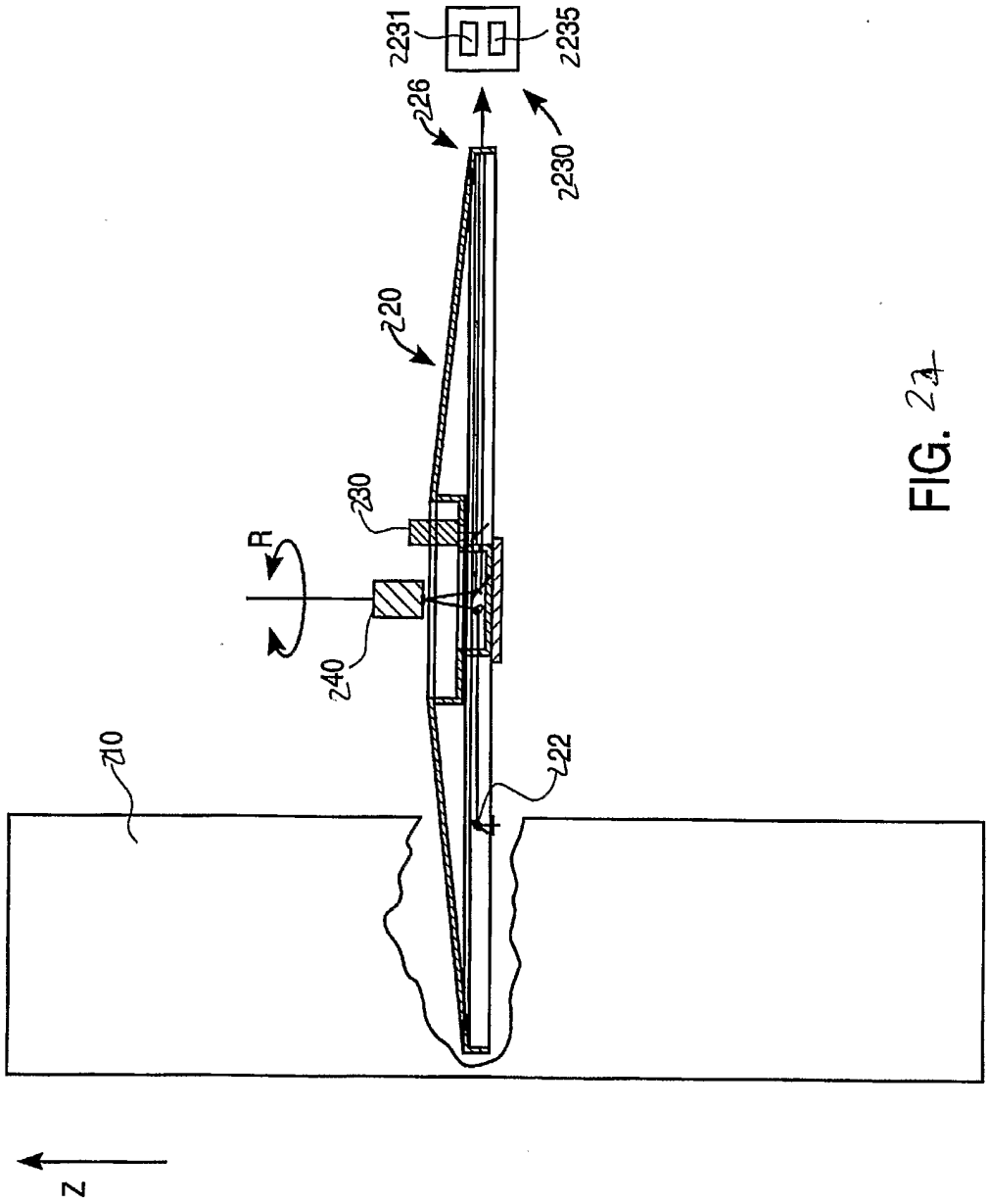


FIG. 24

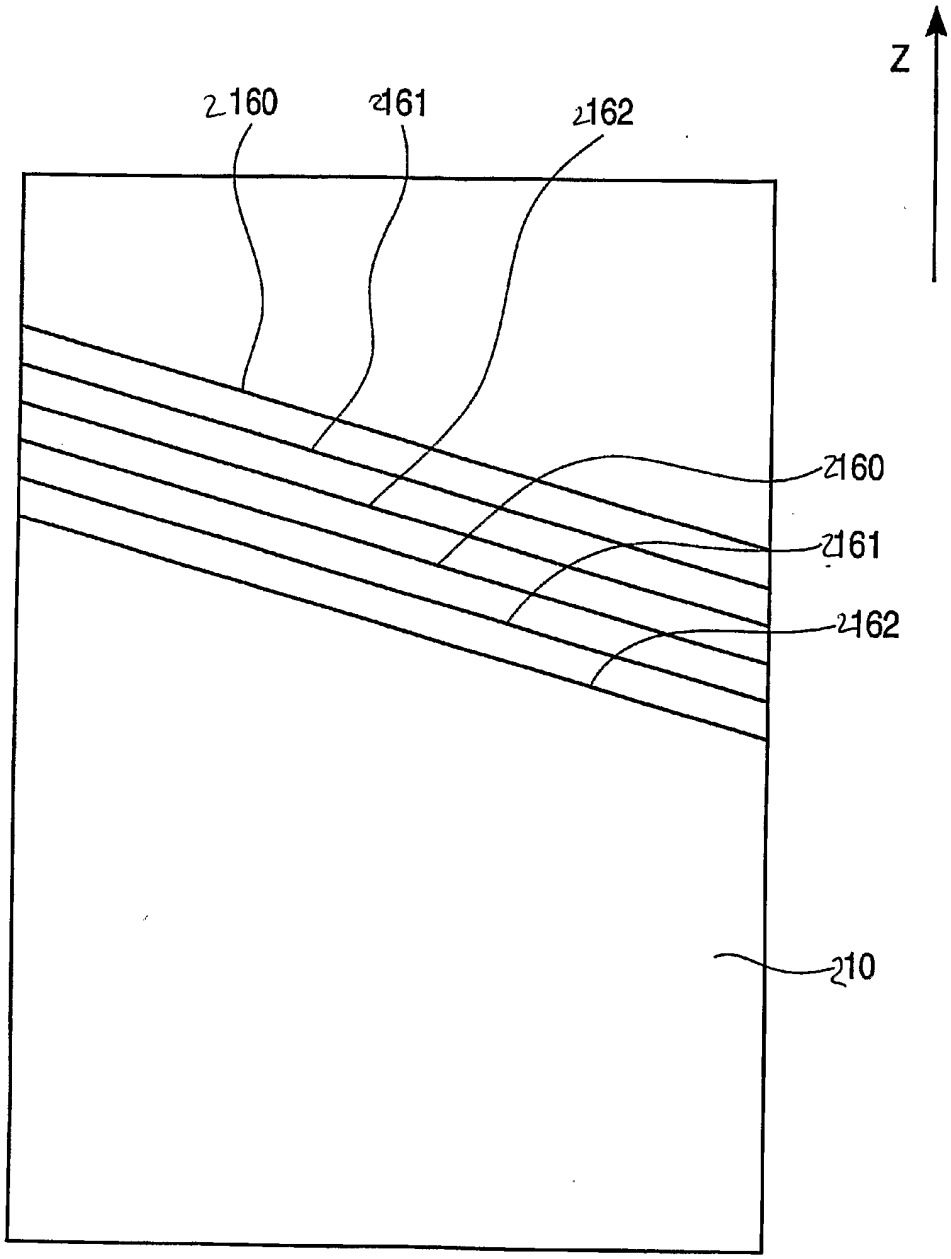


FIG. 23