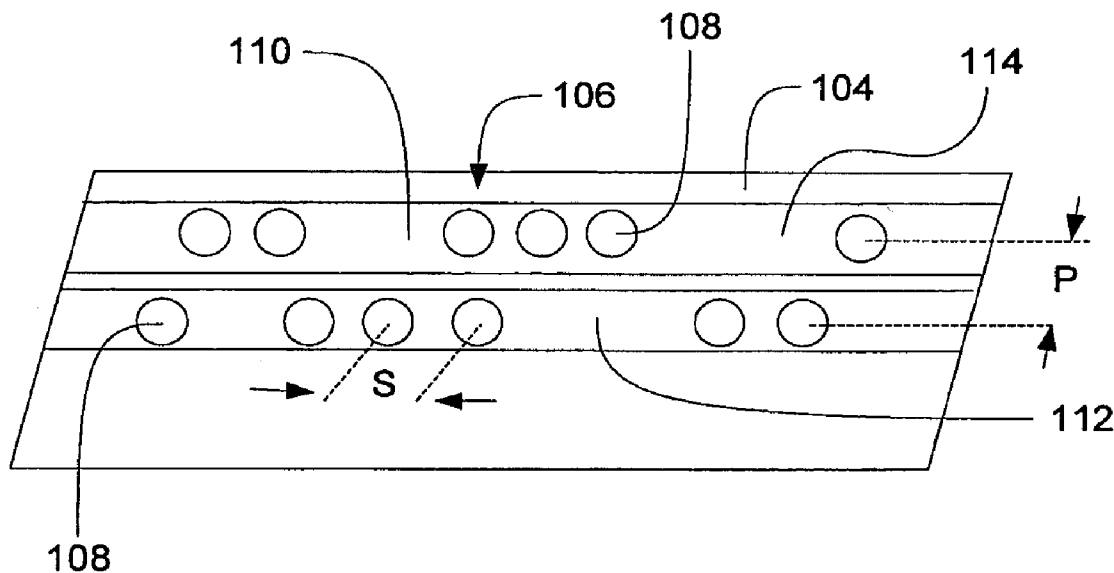




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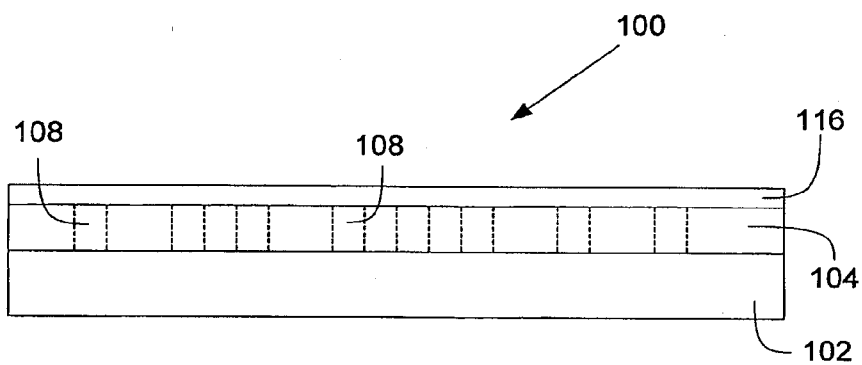


Figure 1

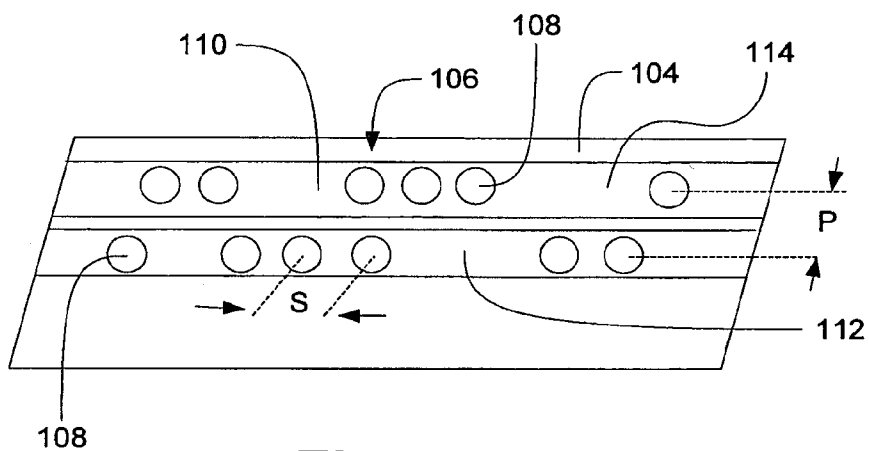


Figure 2A

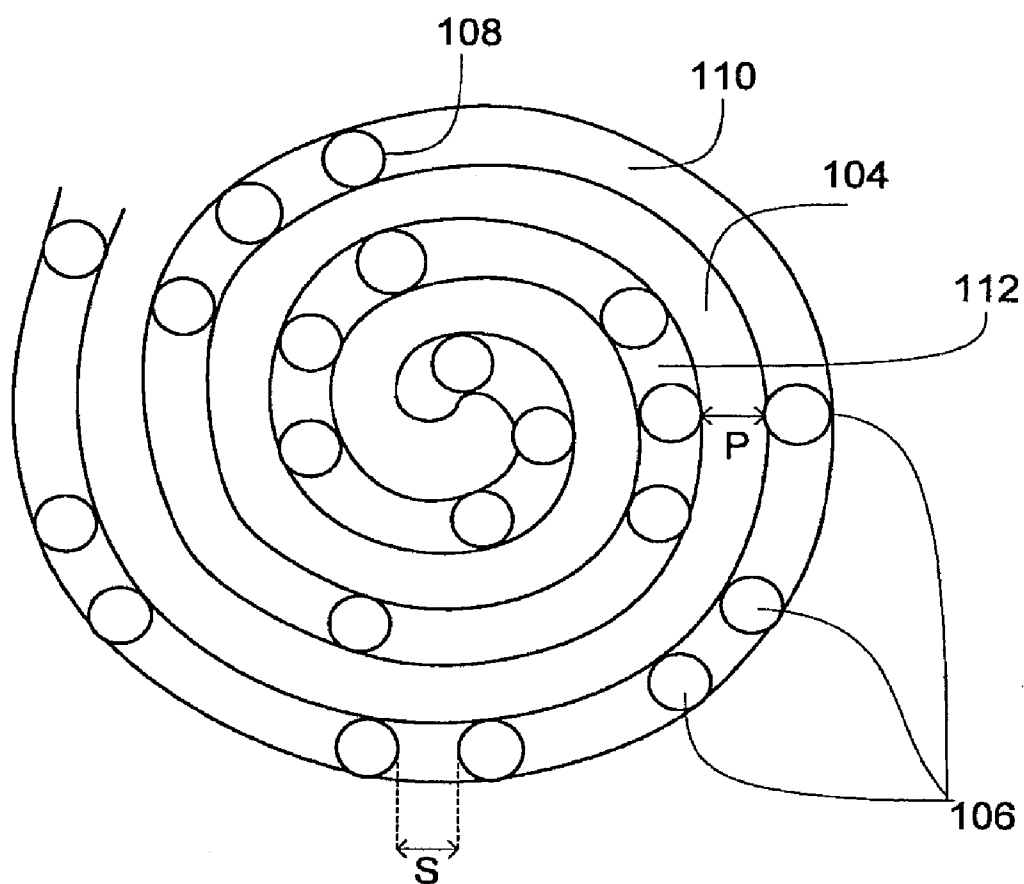


Figure 2B

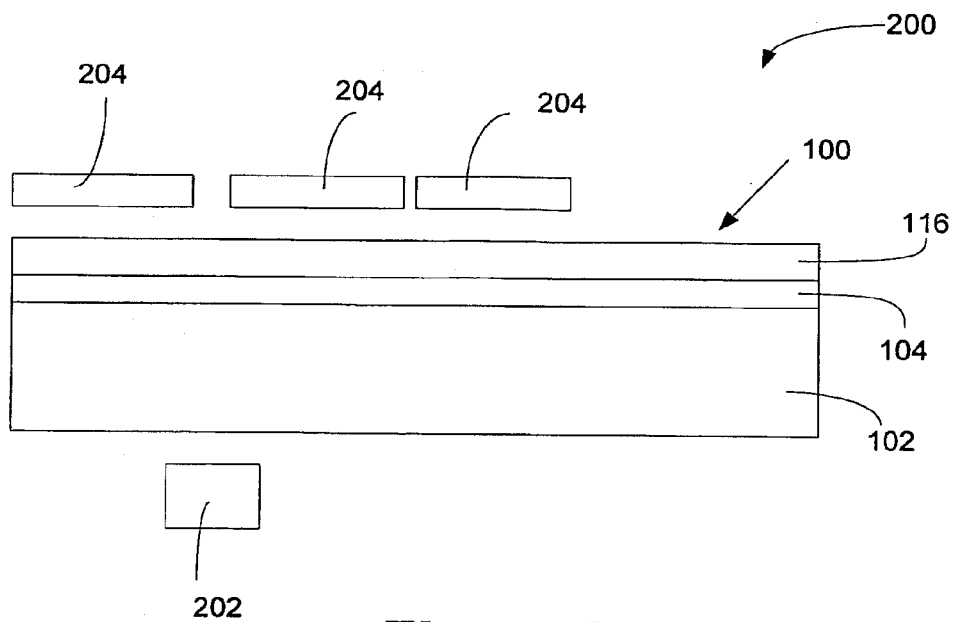


Figure 3

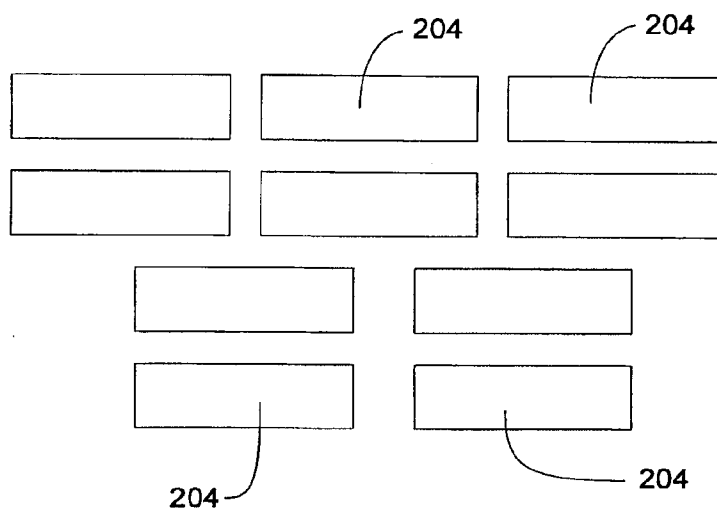


Figure 4

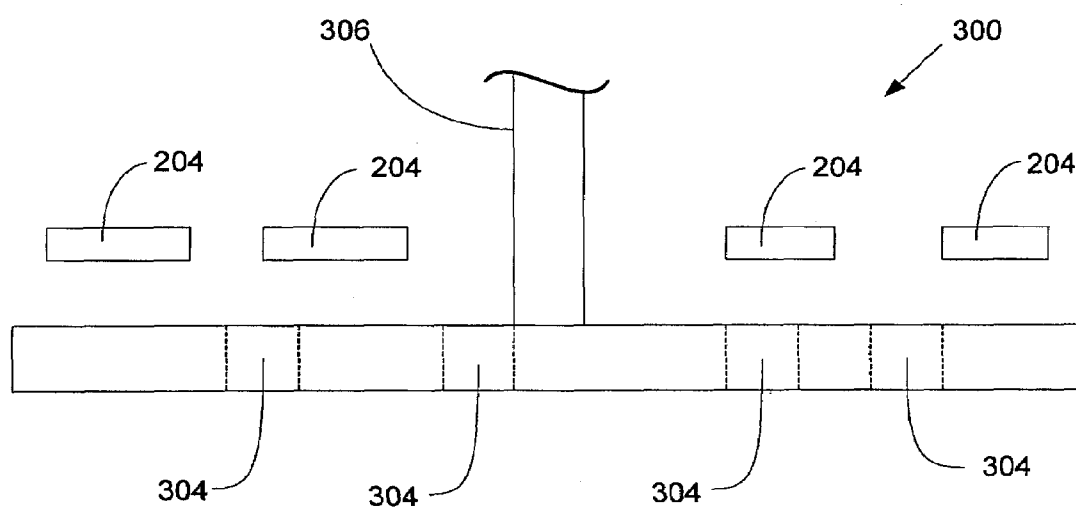


Figure 5

HIGH CAPACITY DIGITAL DATA STORAGE BY TRANSMISSION OF RADIANT ENERGY THROUGH ARRAYS OF SMALL DIAMETER HOLES

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application is a continuation of U.S. patent application Ser. No. 11/370,756 filed Mar. 8, 2006, which is a divisional of U.S. patent application Ser. No. 10/082,928 filed Oct. 19, 2001, now U.S. Pat. No. 7,054,256, which claims benefit to U.S. Provisional Application No. 60/242,042 filed on Oct. 20, 2000 which are hereby incorporated by reference in their entirety.

[0002] This application is also related to U.S. patent application Ser. No. 11/370,758, filed Mar. 7, 2005.

TECHNICAL FIELD

[0003] The present invention relates generally to digital data storage, and more particularly, to high capacity digital data storage.

BACKGROUND

[0004] Compact Discs (CD's) and Digital Versatile Discs (DVD's) have been developed to increase the amount of data that can be stored on a storage medium. These types of storage media have data on them in the form of pits and lands that are written and read with lasers along a track. Generally, the track is helical in shape and each pass of the track is separated from adjacent passes of the track by a track pitch. A standard single sided CD can store approximately 800 Megabytes of data, while a double-sided CD can store 1600 Megabytes of data. A DVD, has a track pitch of about 0.74 microns and a single side/single layer DVD can store about 4.4 Gigabytes of data, which is roughly equivalent to about 2 hours of movie playing time.

[0005] Therefore, some movies and other types of digital content cannot fit on a CD and can very easily be too large to even fit on a DVD. Furthermore, with the advent of certain technologies and business plans for the distribution of "content", it may be advantageous to store a library of digital content, such as movies, on a single removable storage medium. Current CD's and DVD's cannot be used for such purposes.

SUMMARY

[0006] Therefore it is an object of the present invention to provide a data storage medium having a higher storage density than the storage mediums of the prior art.

[0007] A method is provided for making the storage media having data stored thereon. The method comprises: forming a first layer, the first layer being substantially transparent to a predetermined first radiant energy used for reading the data; forming a second layer on the first layer which is substantially opaque to the first radiant energy; and forming a pattern comprising a plurality of holes in the second layer, each of the holes having a largest dimension which is greater than a wavelength of the first radiant energy, the data being stored as the presence or absence of a hole in the pattern.

[0008] Preferably, the first layer is polycarbonate formed by a casting process. The second layer is preferably a metalization coating formed by sputtering the metalization on the first layer.

[0009] The pattern of the plurality of holes are preferably arranged along a helix beginning near a center of the storage

media and extending spirally outward, each successive pass of the helix being separated from a previous pass of the helix by a track pitch.

[0010] The method for making the storage media preferably further comprising forming a third layer on the second layer, the third layer being substantially transparent to the first radiant energy.

[0011] The plurality of holes are preferably formed by x-ray lithography, by melting material in the second layer, or by ablating material in the second layer. Preferably, the plurality of holes are formed by a second radiant energy having a wavelength less than a wave-length of the first radiant energy. The second radiant energy is preferably selected from a group consisting of ultraviolet light, x-rays, and electron beams.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] These and other features, aspects, and advantages of the apparatus and methods of the present invention will become better understood with regard to the following description, appended claims, and accompanying drawings where:

[0013] FIG. 1 illustrates a side view of a representative high capacity digital storage medium in the form of a polycarbonate disk with an opaque layer containing the data holes and a protective coating;

[0014] FIG. 2A illustrates a spiral embodiment of the presently disclosed subject matter;

[0015] FIG. 2B illustrates an enlarged top view of a small portion of the disk of FIG. 1 showing two adjacent track segments;

[0016] FIG. 3 illustrates a side view of a portion of a disk such as the one shown in FIG. 1 with an array of photodetectors on one side of the disk and a light source on the other side of the disk;

[0017] FIG. 4 illustrates a top view of the arrangement shown in FIG. 3; and

[0018] FIG. 5 illustrates a view of portions of one form of a masking arrangement.

DETAILED DESCRIPTION OF ILLUSTRATIVE EMBODIMENTS

[0019] In summary, the present invention is a storage media, and a device and method for storing and reading large amounts of digital data using an array of holes that transmit radiant energy whose wavelength is less than the diameter of the holes. Data is stored on low-cost media by melting or ablating material to form the holes using a light, such as ultraviolet, x-ray or electron beams, with a wavelength shorter than the light used to read back the data. To read the data, intense light is shined on one side of the media as an array of sensitive light detectors on the other side of the media which record and differentiate among the small amounts of light received.

[0020] Referring now to FIGS. 1, 2A, and 2B (not to scale), there is shown a preferred implementation of the storage media of the present invention, generally referred to by reference numeral 100. The storage media 100 is preferably a thin, transparent plastic disk approximately 120 millimeters in diameter, about the size of a conventional CD. Thus, storage media 100 is preferably circular in shape and has a data storage area having an inner diameter of about 25 millimeters and an outer diameter of about 115 millimeters.

[0021] The storage media comprises a first layer 102. The first layer 102 is substantially transparent to a predetermined radiant energy used for reading the data stored on the storage

media **100**. Since, as will be discussed below, the preferred radiant energy source is a light source having a wavelength between 50 and 450 nanometers, the first layer is preferably fabricated from a rigid polycarbonate layer, which is substantially transparent to such wavelength light. The polycarbonate first layer **102** can be fabricated by any methods known in the art, such as by casting.

[0022] The storage media **100** also includes a second layer **104** formed on the first layer **102**. The second layer **104** is substantially opaque to the radiant energy used to read the data stored on the storage media **100**. Using the preferred light source discussed above, the second layer **104** is preferably metallic, such as aluminum. The metallic second layer **104** is preferably formed on the first layer **102** by a metalization process such as sputtering. Such processes are well known in the art. The second layer preferably has a thickness that is thick enough to be opaque to the radiant energy used to read the data from the storage media. Depending on the type of material, this thickness can be on the order of 50 to 250 nanometers, however, it may be more or less without departing from the scope or spirit of the present invention.

[0023] The second layer **104** has a pattern **106** comprising a plurality of holes **108** (alternatively referred to as "data holes"). Each of the holes **108** have a largest dimension which is greater than a wavelength of the radiant energy used to read the data. The data is stored on the storage media **100** as the presence or absence of a hole **108** in the pattern **106**. The plurality of holes **108** are preferably circular where the largest dimension is a diameter of the circular holes **108**. Those skilled in the art will appreciate that other shape holes **108** are possible without departing from the scope or spirit of the invention. Furthermore, those skilled in the art will appreciate that the formation of very small diameter circular holes results in holes that are substantially circular but which may deviate somewhat from a circular shape. The use of the term "circular" is meant to include such deviations.

[0024] The circular holes **108** preferably have a diameter in a range of about 30 to 100 nanometers (nm), more preferably of about 50 nanometers. The distance (S) between successive holes is preferably a hole diameter apart, or in a range of about 30 to 100 nanometers. Similar to the pattern of pits and lands on a conventional CD and DVD, the pattern **106** of holes **108** are preferably arranged along a helix track **110** beginning near a center of the storage media **100** and extending spirally outward. Each successive pass of the helix track is separated from a previous pass of the helix by a track pitch (P). FIGS. 2A and 2B illustrates two successive passes **110**, **112** of the helix track **110**. FIG. 2A approximates the passes **110**, **112** as being linear for clarification purposes, while FIG. 2B shows a portion of the actual helical implementation. In the case where the diameter of the holes **108** is 50 nanometers, the track pitch is preferably 100 nanometers or twice the diameter of the holes **108**. The pattern **106** of holes **108** is formed in the second layer **104** by methods known in the art such as by conventional x-ray lithography as is known in the fabrication of integrated circuits. As discussed above, data is stored on the storage media **100** as the presence or absence of a hole **108** in the overall pattern **106**.

[0025] The storage media **100** preferably further has a third layer **116** formed on the second layer **104**, which acts as a protective coating for the pattern **106** of holes **108**. The third layer **116**, like the first layer **102**, is substantially transparent to the radiant energy used to read the data from the storage media **100**. The third layer **116** is preferably acrylic and is deposited on the second layer **104** by methods known in the art, such as by spraying or chemical vapor deposition depending on the type of material and thickness desired.

[0026] The storage media **100** of the present invention preferably has a size similar to a standard CD, namely having a 120 millimeter diameter disk and having 50 run diameter holes spaced 100 nm center to center (S) as a helix with a track pitch (P) of 100 nm. This helix has a minimum diameter of 25 mm and an outer diameter of 115 mm. Thus, the total length of the helix is about 99,000 meters, and may contain up to 10^{12} (1,000,000,000,000) holes or store up to 125 gigabytes of data. Similarly, using holes that are 30 nm in diameter, with a spacing (S) of 60 nm permits storage of up to 350 gigabytes of data. In the case of a 350 gigabyte capacity disk, the actual capacity may be significantly less when the data is encoded with error correcting codes and alignment rings or holes which are included to facilitate tracking a helical track of holes.

[0027] Referring now to FIGS. 3-5, there is illustrated a schematic representation of an apparatus for reading the data stored on the storage media **100** of the present invention, generally referred to by reference numeral **200**. Conventional components of such a device are well known in the art and are therefore not discussed for the sake of brevity. Such components include, but are not limited to means for retaining the storage media, such as a platter; means for spinning the platter, such as a servo motor; and circuit means for tracking the holes **108**, processing the stored data, and producing a useful result, such as to output the data to a video monitor in a desired format.

[0028] FIG. 3 illustrates the apparatus **200** and a side view of the storage media **100** of FIG. 1 oriented therein. The apparatus **200** includes a radiant energy source **202** having an output of radiant energy directed towards the plurality of data holes **108**. Radiant energy source **202** is preferably a light source such as a blue or uv laser diode, such as those manufactured by Cree, Inc. of Durham, N.C., USA. source **202** preferably operates at 3 mW and produces an intense blue light at about 410 nm. However, it will be appreciated that the light source is preferably in the deep UV to blue range of about 50 nm to 450 nm in wavelength. It should also be appreciated that while radiant energy having wavelengths in this range are preferred, radiant energy below (e.g., x-rays) and above this band may also be used.

[0029] The light source **202** preferably takes the form of a solid-state light emitting diode or laser diode, formed from a wide bandgap material such as silicon carbide. Other wide bandgap materials include gallium arsenide, gallium nitride, aluminum nitride, zinc selenide, gallium nitride/aluminum nitride alloy, aluminum nitride/silicon carbide alloy and aluminum gallium nitride/gallium nitride heterojunctions, which, as known in the art, will produce light at a wavelength that is determined primarily by the bandgap of the semiconductor material. However, silicon carbide detectors are favored because they have the advantages of sensitivity that peaks in the range of deep blue and ultraviolet, extremely low dark current so that extremely small light levels can be detected, and relatively low fabrication costs.

[0030] Apparatus **200** also includes an array of detectors **204** arranged on an opposite side of the disk from the radiant energy source **202**. The plurality of detectors **204** are preferably photodetectors and detect the radiant energy from the radiant energy source **202** diffusing from the plurality of data holes. The radiant energy source **202** is preferably positioned on the side of the storage media **100** having the first layer **102** and is directed towards the detectors **204** that are positioned on the side of the storage media **100** opposite the first layer **102** (e.g., proximate to the second and third layers **104**, **116**).

[0031] When used with a radiant energy source **202** in the form of a light source **202**, the discrete photodetectors **204** of

the photodetector array are sensitive to light at the wavelength of the light source **202**. In a preferred implementation, photodetectors **204** take the form of model no. CD-260-1-00-D silicon carbide ultraviolet photodetector chips manufactured by Cree, Inc. of Durham, N.C., USA. These photodetectors have extraordinary responsibility to light in a band including the wavelength of the light source **202** and have exceptionally low dark current. Further details for the manner in which photodetectors **204** are preferably arranged is shown in the top view of FIG. 4.

[0032] Likewise, photodetectors used in accordance with the invention are preferably solid-state devices such as the mentioned Cree, Inc. silicon carbide photodetectors, where the responsivity curve of the photodetector matches the wavelength of the light output by the light source **202**. Solid state photodetectors may be formed to match the light source from various wide bandgap semiconductor materials, including silicon carbide and the others mentioned above.

[0033] To read the data stored on the storage media **100**, the storage media **100**, in the form of a disk, is slowly spun while the source of radiant energy **202**, for example, the blue or UV laser diode, is preferably focused into about a 1 micrometer diameter area on one side of the storage media disk **100** while the array of photodetectors **204** on the other side of the storage media disk **100** sense light passing through and diffusing from the holes **108** formed on the storage media **100**.

[0034] The detectors **204** may be arrayed in a brick-like pattern as illustrated in FIG. 4. The brick array of detectors **204** may have redundant detector elements so that not all detector elements need to be operational. Thus, even flawed detector arrays are usable so that fabrication costs will be lessened by excellent yields.

[0035] Referring now to FIG. 5, a masking means is illustrated, generally referred to by reference numeral **300**. The masking means **300** masks the detectors **204** to restrict the number of holes **108** observed by a single detector **204**. The masking means **300** is carried by a servo mechanism of the tracking system (not shown) used to track the holes **108**. Masking means **300** includes a mask body **302** with masking openings **304** preferably having a diameter corresponding to the diameter of holes **108** in the second layer **104**, for example, 50 run. Mask body **62** is attached to the servo mechanism by a mounting member **306**. In a preferred implementation of the apparatus **200** for reading the data stored on the storage media **100**, individual detectors **204** are masked with masking openings in the form of rectangles such that the sides of the rectangles approximate the diameters of the holes **108** in the media. The mask body **302** is preferably sufficiently thick so that the masking openings **304** act both as apertures and tunnels in reducing interference from light flowing through nearby data holes **108**. The mask body **302** on the detector array is preferably also held very close to the surface of the storage media **100** to minimize crosstalk between neighboring holes. In an alternate implementation, a lens (not shown) positioned between the array of detectors **204** and the mask body **302** avoids the need to closely position the array against the mask body while still limiting crosstalk of light between adjacent holes.

[0036] The use of strong blue, deep blue and ultraviolet laser diodes and corresponding high-sensitivity photoelectric sensors makes possible this new type of optical storage medium based upon the weak transmission of light through extremely tiny holes (or blocked by extremely tiny objects). By nature of the substrates used to produce photoelectric sensors, sensors for very short wavelengths have extraordinarily small dark currents so that with proper amplification, extremely small quantities of light can be measured without

requiring cooling. Furthermore, because sensors can be fabricated by an inexpensive process, arrays of these sensors can be made reliably for a very low per-pixel cost. Furthermore, by fabrication of arrays of these sensors on a single substrate, perhaps several millimeters square, following the path of the holes on the storage media can be accomplished by completely electronic means (except for a relatively imprecise mechanical motor and gearing to slowly step the small array across the radius of the storage media).

[0037] It is also possible to use the array of sensors to read multiple tracks of the helix simultaneously, allowing a slower rotation of the storage media or higher data rates than are currently possible with conventional media such as a CD. For example, simultaneous reading of ten tracks would allow the storage media to move at a speed of 30 mm/sec by turning at a rate of about 5 to 30 rpm.

[0038] Those skilled in the art will appreciate that the high capacity digital data storage media of the present invention allows low cost distribution of data. For example a 125 gigabyte disk may store about 100 movies that can be decompressed and played with VHS quality, or it may store the music from the 1000 CD's, again using typical audio compression techniques such as MPEG-3 or AAC. Use of higher compression techniques would permit the storage of even more movies and/or CD's on such a disk. This low-cost storage media presents an opportunity for new and advantageous business models for the mass distribution of movies and/or music to consumers. While there has been shown and described what is considered to be preferred embodiments of the invention, it will, of course, be understood that various modifications and changes in form or detail could readily be made without departing from the spirit of the invention. It is therefore intended that the invention be not limited to the exact forms described and illustrated, but should be constructed to cover all modifications that may fall within the scope of the appended claims.

What is claimed:

1. An apparatus for reading a storage medium, comprising:
 - a plurality of emitters configured to emit a radiant energy at a predetermined optical wavelength;
 - a plurality of detectors configured to detect the radiant energy at the predetermined optical wavelength; and
 - a storage medium holder configured to hold the storage medium between the plurality of emitters and the plurality of detectors;

wherein a first emitter of the plurality of emitters is configured to emit the radiant energy toward data holes of a first track of the storage medium, and a first detector of the plurality of detectors is configured to detect the radiant energy from the first emitter which passes through the data holes of the first track of the storage medium; and

wherein a second emitter of the plurality of emitters is configured to emit the radiant energy toward data holes of a second track of the storage medium, and a second detector of the plurality of detectors is configured to detect the radiant energy from the second emitter which passes through the data holes of the second track of the storage medium.

2. The apparatus of claim 1, wherein the storage medium holder is configured to hold a storage medium comprising an opaque layer having a pattern of data holes, wherein at least one of the data holes has a largest dimension which is greater than the predetermined optical wavelength of a radiant energy, and the data is stored as a presence or an absence of a data hole in the pattern, wherein the radiant energy is config-

ured to pass through the data holes at substantially the same predetermined optical wavelength.

3. The apparatus of claim 1, wherein the plurality of emitters and the plurality of detectors are configured to simultaneously detect the radiant energy from the first emitter which passes through the data holes of the first track and the radiant energy from the second emitter which passes through the data holes of the second track.

4. The apparatus of claim 1, wherein the plurality of detectors is configured to detect radiant energy passing through data holes of each of ten tracks of the storage medium.

5. The apparatus of claim 4, wherein the detection of the plurality of detectors is further configured to simultaneously detect the radiant energy passing through the data holes of each of the ten tracks

6. The apparatus of claim 1, wherein the data holes of the storage medium are arranged in a helical pattern on the storage medium.

7. The apparatus of claim 6, wherein the holder is configured to rotate the storage medium at a rate between about 5 rotations per minute to about 30 rotations per minute during the detection of the radiant energy by the plurality of detectors.

8. A method for reading multiple tracks of a storage medium comprising an opaque layer having a pattern of data holes, wherein at least one of the data holes has a largest dimension which is greater than a predetermined optical wavelength of a radiant energy, and the data is stored as a presence or an absence of a data hole in the pattern, wherein the radiant energy is configured to pass through the data holes at substantially the same predetermined optical wavelength, the method comprising:

holding the storage medium between a plurality of emitters and a plurality of detectors, wherein the plurality of emitters comprises a first emitter and a second emitter, and the plurality of detectors comprises a first detector and a second detector;

directing the radiant energy at the predetermined wavelength from the first emitter toward the data holes of a first track of the storage medium;

detecting, by the first detector, the radiant energy which passes through the data holes of the first track;

directing radiant energy at the predetermined wavelength from the second emitter toward the data holes of a second track of the storage medium;

detecting, by the second detector, the radiant energy which passes through the data holes of the first track.

9. The method of claim 8, wherein the detecting by the first detector and the detecting by the second detector occur at least partially simultaneously.

10. The method of claim 8, further comprising:

detecting, by the plurality of detectors, radiant energy which passes through data holes of each of ten tracks of the storage medium.

11. The method of claim 10, wherein the detecting radiant energy which passes through data holes of each of ten tracks occurs at least partially simultaneously.

12. The method of claim 8, wherein the data holes of the storage medium are arranged in a helical pattern on the storage medium.

13. The method of claim 8, further comprising rotating the storage medium at a rate between about 5 rotations per minute to about 30 rotations per minute during the detection of the radiant energy by the plurality of detectors.

14. An apparatus for reading a storage medium, comprising:

a means for emitting radiant energy at a predetermined optical wavelength;

a means for detecting radiant energy at the predetermined optical wavelength;

a means for holding the storage medium between the means for emitting and the means for detecting;

wherein the means for emitting is configured to emit the radiant energy toward data holes of a first track of the storage medium, and the means for detecting is configured to detect the radiant energy which passes through the data holes of the first track of the storage medium;

wherein the means for emitting is further configured to emit the radiant energy toward data holes of a second track of the storage medium, and the means for detecting is further configured to detect the radiant energy which passes through the data holes of the second track of the storage medium.

15. The apparatus of claim 14, wherein the means for holding a storage medium comprises means for holding a storage medium comprising an opaque layer having a pattern of data holes, wherein at least one of the data holes has a largest dimension which is greater than the predetermined optical wavelength of a radiant energy, and the data is stored as a presence or an absence of a data hole in the pattern, wherein the radiant energy is configured to pass through the data holes at substantially the same predetermined optical wavelength, the apparatus.

16. The apparatus of claim 14, wherein the means for detecting is configured to simultaneously detect the radiant energy which passes through the data holes of the first track and the radiant energy which passes through the data holes of the second track.

17. The apparatus of claim 14, wherein the means for detecting is configured to detect radiant energy passing through data holes of each of ten tracks of the storage medium.

18. The apparatus of claim 17, wherein the means for detecting is further configured to simultaneously detect the radiant energy passing through the data holes of each of the ten tracks.

19. The apparatus of claim 14, wherein the data holes of the storage medium are arranged in a helical pattern on the storage medium.

20. The apparatus of claim 19, wherein the means for holding is configured to rotate the storage medium at a rate between about 5 rotations per minute to about 30 rotations per minute during the detection of the radiant energy by the means for detecting.

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