

A DATA STORAGE DEVICE

Field Of Invention

The present invention relates generally to a data storage device. In particular, the invention relates to a data storage device that utilizes different physical properties of a laser beam for providing a multi-level data storage structure capable of multi-dimensional data storage for achieving a high-density and high data transfer rate optical recording medium.

10 Background

Optical data storage density is typically determined by the diameter of a light spot formed on a recording surface by irradiation of laser. The diameter d of the light spot is described as:

$$d = \frac{\lambda}{(2NA)}$$

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where λ is the wavelength of the laser and NA is the numerical aperture. A smaller minimum spot diameter results in higher density data recording and storage. Therefore, in order to increase the recording density of an optical recording medium, shorter wavelength of laser and higher numerical aperture (NA) of objective lenses are used. However, there are disadvantages to shortening the wavelength of the laser and increasing the numerical aperture to achieve higher recording density. A coma created by a tilted optical disk increases proportionally in magnitude to the cube of the numerical aperture. Therefore, a larger numerical aperture results in a substantially smaller margin for angular tilt of the optical disk. Tilting the optical disk slightly causes the laser to create a blurred spot thereon, thereby resulting in higher recording density not being achievable.

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It is known in the art that a Blu-ray disk (Blu-ray being a trademark of Sony Corporation) has a recording density of not less than 23 GB and a data transfer rate as high as 36 MBps. However, the optical system of the Blu-ray disk uses a laser wavelength of 405 nm and an objective lens with a numerical aperture of 0.85. As a result, the Blu-ray disk requires a thin light transmission layer of about 0.1 mm to

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achieve a sufficient tilt margin. Unfortunately, such a thin light-transmission layer cannot be produced by conventional injection molding machines. Furthermore, its strict thickness variation within a tolerance of 0.2 μm results in relatively higher production cost when compared with conventional optical disks. Additionally, a shorter working distance of approximately 0.3mm limited by use of the high numerical aperture objective lens leads to a higher risk of collision between the optical disk and the lens.

Use of multiple recording layers is also known in the art for achieving high recording density. For example, a dual-layer optical recording medium was proposed in order to double the recording density by recording on two recording layers from the same side of the disk. However, it is a technical challenge to achieve large transmittance for the first layer of the dual layers as a material, for example a phase change material, becomes less transparent to laser with increased thickness.

PCT Publication No. 02/063620 A2 (Arieli) discloses a solution for overcoming the problem that during the reading process, each layer interferes optically with the other layers. Arieli describes an optical data storage device comprising multiple recording layers and a focusing system for focusing laser onto the intended recording layer for reading therefrom. However, the need for refocusing the laser for the different recording layers in Arieli results in a slower rate of data retrieval. Furthermore, the recording density of each recording layer is dependent on the accuracy of the focusing system.

US Patent No. 5,838,653 (Fan) discloses an optical information storage system comprising multiple information storage layers. Each storage layer or portion thereof is wavelength-specific and polarization-specific. Information can only be read from a particular storage layer by a laser beam with a specific wavelength and polarization corresponding therewith. However, Fan requires a spectrum of lasers catering to the range of wavelengths and polarizations required. The use of a modulator for varying the wavelength and polarization of a single laser is complex and slows the rate of data retrieval.

Hence, this clearly affirms a need for an improved data storage system with high recording density and high data transfer rate.

5 **Summary**

A data storage device described hereinafter comprises a substrate and a recording layer having a phase change layer and a magneto-optical layer formed on the substrate. The data storage device utilizes two physical properties, namely, amplitude and polarization level of laser reflected therefrom. Laser directed at the data storage
10 device penetrates the substrate or the cover layer to heat up said recording layer. By adjusting the laser's power, the phase change layer can be switched between a crystalline state and an amorphous state. The phase change layer in the completely amorphous state provides 0% of relative reflectance while the phase change layer in the completely crystalline state provides 100% of reflectance. Discretised variation in
15 the laser's power provides for different possible reflectance levels. Therefore, multi-level recording can be realized in the phase-change recording layer using different levels of reflectance.

When the laser is directed onto said recording layer, the magneto-optical layer is
20 heated up concurrently. When the temperature of the magneto-optical layer reaches the Curie temperature, or the Compensation temperature, thereof, a bias magnetic field is applied to vary the polarization level in the magneto-optical layer. The polarization of the reflected or transmitted laser or light beam can be detected through magneto-optical effects. Therefore, the reflectance amplitude and the polarization
25 level of laser reflected from the data storage device are combined to provide a medium for multi-dimensional multi-level recording and storage.

Therefore, in accordance with a first aspect of the invention, there is disclosed a data storage device comprising:

30 a first recording layer having a first face and a second face outwardly opposing the first face, the first recording layer having a first plurality of data storage locations, each of the first plurality of data storage locations having a first physical property being variable through at least two states for indicating a first data value;

a second recording layer stacked adjacent to the second face of the first recording layer, the second recording layer having a second plurality of data storage locations, each of the second plurality of data storage locations having a second physical property being variable through at least two states for indicating a second data value, the first physical property being distinct from the second physical property; and

a plurality of data axes formed substantially perpendicular to the second face of the first recording layer, each of the plurality of data axes extending through a corresponding one of the first plurality of data storage locations and a corresponding one of the second plurality of data storage locations,

wherein a processed beam having first and second beam properties is processed from a laser beam directed towards the first and second recording layers along one of the plurality of data axes, the laser beam being processed initially by the corresponding one of the first plurality of data storage locations with one of the at least two states thereof determining the first beam property, and subsequently by the corresponding one of the second plurality of data storage locations with one of the at least two states thereof determining the second beam property, the first and second beam properties of the processed beam being respectively indicative of the first and second data values of the corresponding one of the first plurality of data storage locations and the corresponding one of the second plurality of data storage locations.

In accordance with a second aspect of the invention, there is disclosed a data storage device comprising:

a first recording layer having a first face and a second face outwardly opposing the first face, the first recording layer being made from a first material and having a first plurality of data storage locations, each of the first plurality of data storage locations having a first physical property being variable through at least two states for indicating a first data value;

a second recording layer stacked adjacent to the second face of the first recording layer, the second recording layer being made from a second material and having a second plurality of data storage locations, each of the second plurality of data storage locations having a second physical property being variable through at least two states for indicating a second data value, the first physical property being

distinct from the second physical property, wherein the first physical property is reflectance and the second physical property is optical polarization with one of the at least two states of each of the first plurality of data storage locations corresponding with reflectance level thereof and one of the at least two states of each of the second plurality of data storage locations corresponding with optical polarization level thereof, the first material being a phase change material with the at least two states thereof being at least two crystallinity levels, and the second material being a magneto-optical material with the at least two states thereof being at least two polarization states; and

a plurality of data axes formed substantially perpendicular to the second face of the first recording layer, each of the plurality of data axes extending through a corresponding one of the first plurality of data storage locations and a corresponding one of the second plurality of data storage locations,

wherein a processed beam having first and second beam properties is processed from a laser beam directed towards the first and second recording layers along one of the plurality of data axes, the laser beam being processed initially by the corresponding one of the first plurality of data storage locations with one of the at least two states thereof determining the first beam property, and subsequently by the corresponding one of the second plurality of data storage locations with one of the at least two states thereof determining the second beam property, the first and second beam properties of the processed beam being respectively indicative of the first and second data values of the corresponding one of the first plurality of data storage locations and the corresponding one of the second plurality of data storage locations.

In accordance with a third aspect of the invention, there is disclosed a data storage device comprising:

a first recording layer having a first face and a second face outwardly opposing the first face, the first recording layer being made from a first material and having a first plurality of data storage locations, each of the first plurality of data storage locations having a first physical property being variable through at least two states for indicating a first data value;

a second recording layer stacked adjacent to the second face of the first recording layer, the second recording layer being made from a second material and

having a second plurality of data storage locations, each of the second plurality of data storage locations having a second physical property being variable through at least two states for indicating a second data value, the first physical property being distinct from the second physical property, wherein the first physical property is optical polarization and the second physical property is reflectance with one of the at least two states of each of the first plurality of data storage locations corresponding with optical polarization level thereof and one of the at least two states of each of the second plurality of data storage locations corresponding with reflectance level thereof, the first material being a magneto-optical material with the at least two states thereof being at least two polarization states and the second material being a phase change material with the at least two states thereof being at least two crystallinity levels; and

a plurality of data axes formed substantially perpendicular to the second face of the first recording layer, each of the plurality of data axes extending through a corresponding one of the first plurality of data storage locations and a corresponding one of the second plurality of data storage locations,

wherein a processed beam having first and second beam properties is processed from a laser beam directed towards the first and second recording layers along one of the plurality of data axes, the laser beam being processed initially by the corresponding one of the first plurality of data storage locations with one of the at least two states thereof determining the first beam property, and subsequently by the corresponding one of the second plurality of data storage locations with one of the at least two states thereof determining the second beam property, the first and second beam properties of the processed beam being respectively indicative of the first and second data values of the corresponding one of the first plurality of data storage locations and the corresponding one of the second plurality of data storage locations.

Brief Description Of The Drawings

Embodiments of the invention are described hereinafter with reference to the following drawings, in which:

FIG. 1 shows a partial front sectional elevation of a data storage device with a first recording layer and a second recording layer formed on a substrate according to a first embodiment of the invention;

FIG. 2 shows a partial front sectional elevation of the data storage device of FIG. 1 with a reflective layer formed on the second recording layer according to a second embodiment of the invention;

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FIG. 3 shows a partial front sectional elevation of the data storage device of FIG. 2 with a first protective layer and a second protective layer formed therein according to a third embodiment of the invention;

10 FIG. 4 shows a partial front sectional elevation of the data storage device of FIG. 3 with an interface layer formed between the first recording layer and the second recording layer according to a fourth embodiment of the invention;

FIG. 5 shows a partial front sectional elevation of the data storage device of FIG. 3 with the substrate being replaced by a cover layer and the substrate being formed over the reflective layer according to a fifth embodiment of the invention; and

FIG. 6 shows a partial front sectional elevation of the data storage device of FIG. 4 with the substrate being replaced by a cover layer and the substrate being formed over the reflective layer according to a fifth embodiment of the invention.

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Detailed Description

A data storage device is described hereinafter for addressing the foregoing problems.

25 A first embodiment of the invention, a data storage device 20, is described with reference to FIG. 1, which shows a partial front sectional elevation of the data storage device 20.

As shown in FIG. 1, the data storage device 20 comprises a substrate 22 and a storage layer 24 stacked adjacent to the substrate 22. The substrate 22 and the storage layer 24 are shaped and dimensioned to provide the data storage device 20 with preferably a disc shape.

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The storage layer 24 comprises a first recording layer 26 and a second recording layer 28. The first recording layer 26 has a first face 30a and a second face 30b outwardly opposing the first face 30a. The second recording layer 28 is stacked adjacent to the second face 30b of the first recording layer 26 with the substrate 22 opposing the first face 30a of the first recording layer 26.

The substrate 22 is for structurally supporting the first recording layer 26 and the second recording layer 28. The substrate 22 is preferably made from one of polycarbonate, polymethyl methacrylate (PMMA), amorphous polyolefin, ceramic and glass. The substrate preferably has a thickness within a range of 0.1mm to 1.2mm and a diameter of, for example, substantially 120mm.

The first recording layer 26 comprises a first plurality of data storage locations 32a and the second recording layer 28 comprises a second plurality of data storage locations 32b. The first recording layer 26 is made from a first material with each of the first plurality of data storage locations 32a having a first physical property being variable through at least two states for indicating a first data value. The second recording layer 28 is made from a second material with each of the second plurality of data storage locations 32b having a second physical property and being variable through at least two states for indicating a second data value.

The first material and the second material are preferably different with the first physical property being different and distinct from the second physical property. Alternatively, the first material and the second material are the same. At least one of the first material and the second material is process-treatable to thereby differentiate the first physical property from the second physical property. Alternatively, the fabrication process of at least one of the first recording layer 26 and the second recording layer 28 is alterable for differentiating the first physical property from the second physical property.

The data storage device 20 further comprises data axes 46 formed substantially perpendicular to the second face 30b of the first recording layer 26. Each data axis 46 extends correspondingly through one of the first plurality of data storage locations 32a

or one of the second plurality of data storage locations 32b. A laser beam 48 is directable towards the first recording layer 26 and the second recording layer 28 along one of the data axes 46 to obtain a processed beam 50 therefrom. The laser beam 48 is directed through the substrate 20 which is preferably light transmissible. The
 5 processed beam has a first beam property and a second beam property.

The laser beam 48 coincides with each of the first recording layer 26 and the second recording layer 28 for forming a mark on each of the first recording layer 26 and the second recording layer 28, with the mark on each thereof being coincident with one of
 10 the first plurality of data storage locations 32a and one of the second plurality of data storage locations 32b respectively and being representative of data.

When the laser beam 48 is directed towards the first face 30a of the first recording layer 26 along the one of the data axes 46, the laser beam 48 is processed initially by
 15 the corresponding one of the first plurality of data storage locations 32a with one of the at least two states thereof determining the first beam property, and subsequently by the corresponding one of the second plurality of data storage locations 32b with one of the at least two states thereof determining the second beam property. The determined first beam property and second beam property of the processed beam 50
 20 indicates the first data value and second data value of the corresponding one of the first plurality of data storage locations 32a and the corresponding one of the second plurality of data storage locations 32b respectively.

The first physical property is preferably reflectance and the second physical property
 25 is preferably optical polarization. However, the first physical property and the second physical property of the invention, the data storage device 20, are respectively not limited to reflectance and optical polarisation. One of the at least two states of each of the first plurality of data storage locations 32a corresponds with reflectance level thereof and one of the at least two states of each of the second plurality of data storage
 30 locations 32b corresponds with optical polarization level thereof.

The first material is preferably made from a combination of one or more elements, for example, chalcogenide elements. The one or more elements are preferably selected

from Te, Ge, Sb, Te, Bi, Pd, Sn, As, Ag, In, Se, S, Si, P and organic recording materials. The first material enables the first recording layer 26 to function as a phase change material with the at least two states thereof being at least two crystallinity levels. The first physical property is variable between a substantially crystalline state and a substantially amorphous state with the at least two crystallinity levels extending and forming graduations therebetween. Therefore, varying a portion of the first recording layer 26 between the substantially crystalline state and the substantially amorphous state varies at least one of reflectance and transmittance of the portion of the first recording layer 26.

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The first physical property of the first material is variable by the laser beam 48 having a magnitude which corresponds with the at least two crystallinity levels.

When the corresponding one of the first plurality of data storage locations 32a is in a completely amorphous state, a substantially low reflectance is achieved. Increasing the crystallinity of the corresponding one of the first plurality of data storage locations 32a results in an increase of the reflectance thereof. When the corresponding one of the first plurality of data storage locations 32a is in a completely crystalline state, a substantially high reflectance is achieved.

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The second material is preferably made from a combination of one or more of Fe, Co and Ni and one or more of Tb, Cr, Gd, Mn, Pt, Pd, Al, Au, Ag, Cu, Mg. The second material enables the second recording layer 28 to function as a magneto-optical material with the at least two states thereof being at least two polarization states. The second physical property of the second material is variable between two optical polarization levels with the at least two polarization states extending and forming graduations therebetween. Therefore, varying the second physical property of a portion of the second recording layer 28 between the two optical polarization levels varies the at least two polarization states of the portion of the second recording layer 28.

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The second recording layer 28 preferably has substantial magnetic anisotropy with the second material having high cohesive forces to enable small recording data bits to be

formed, thereby increasing the quantity of the second plurality of data storage locations 32b on the second recording layer 28.

5 The second physical property of the second material is variable by heat generated by the laser beam 48 on the portion of the second material to achieve the Curie temperature, or the compensation temperature, thereof and a field direction of a magnetic field applied thereto. The magnetic field is generated by one of a permanent magnet and an electromagnet.

10 Each of the first recording layer 26 and the second recording layer 28 is formed by deposition of the corresponding one of the first material and the second material by one of vacuum deposition, electron beam vacuum deposition, ion plating, chemical vapor deposition, plasma CVD, laser deposition, spinning coating, molecular beam epitaxy and sputtering methods.

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Preferably, the first recording layer 26 and the second recording layer 28 are being doped by further sputtering of a mixture comprising Argon and at least one of Nitrogen and Oxygen thereto.

20 Magnitude ranges and level ranges are preferably pre-defined to facilitate use of the data storage device 20. The magnitude ranges are associated with a first plurality of values comprising the first data value. The level ranges are associated with a second plurality of values comprising the second data value.

25 The first beam property and the second beam property of the processed beam 50 are respectively magnitude and optical polarization level thereof. Therefore, detection of the magnitude and the optical polarization level of the processed beam 50 and identifying one of the magnitude ranges and one of the level ranges corresponding therewith enables the corresponding one of the plurality of first values and the
30 corresponding one of the plurality of second values to be identified.

Therefore, the first data value and the second data value are stored on respectively the first recording layer 26 and the second recording layer 28 at one of the plurality of

data storage locations 32a/32b of each thereof wherefrom the processed beam 50 is reflected to obtain the corresponding one of the plurality of first values and the corresponding one of the plurality of second values.

- 5 The one of the first plurality of data storage locations 32a and the one of the second plurality of data storage locations 32b along each of the data axes 46 collectively store at least two numerical bits of data in combination.

However, it is possible to achieve four distinguishable states for the first physical
10 property, for example four distinct levels of reflectance, and two distinct states for the second physical property, for example two polarization levels. Therefore, the one of the first plurality of data storage locations 32a and the one of the second plurality of data storage locations 32b along each of the data axes 46 can collectively achieve a combined 8 levels of recording translating to 3 binary bits of data storage thereat. The
15 first recording layer 26 and the second recording layer 28 provide a multi-level recording structure to the data storage device 20. The variable first physical property of each of the first plurality of data storage locations 32a and the variable second physical property of each of the second plurality of data storage locations 32b cater to the multi-dimensional data recording capability of each of the first recording layer 26
20 and the second recording layer 28. Therefore, the storage device 20 functionally achieves a multi-dimensional multi-level optical recording medium.

Additionally, one of an AND operator, an OR operator, a NAND operator and a NOR operator is applicable to the obtained first data value and second data value to obtain
25 further data therefrom.

A second embodiment of the invention, a data storage device 70 as shown in FIG. 2, comprises two main elements: a substrate 22 and a storage layer 24 having a first recording layer 26 and a second recording layer 28. The descriptions in relation to the
30 structural configurations of and positional relationships between the substrate 22 and the storage layer 24 and the first plurality of data storage locations 32a and the second plurality of data storage locations 32b corresponding with the first recording layer 26

and the second recording layer 28 with reference to the first embodiment of FIG. 1 are incorporated herein.

The data storage device 70 further comprises a reflective layer 72 stacked adjacent to a face of the second recording layer 28 which faces away from the first recording layer 26. The reflective layer 72 is for dissipating excessive heat accumulated during data read/write processes wherein heat is generated by the laser beam 48 upon its application to the second recording layer 28. The reflective layer 72 is made from at least one of Au, Al, Ag, Ti, Cr, Cu, Pd, W and Pt.

A third embodiment of the invention, a data storage device 80 as shown in FIG. 3, comprises three main elements: a substrate 22, a storage layer 24 having a first recording layer 26 and a second recording layer 28, and a reflective layer 72. The descriptions in relation to the structural configurations of and positional relationships between the substrate 22, the storage layer 24 and the reflective layer 72 and the first plurality of data storage locations 32a and the second plurality of data storage locations 32b corresponding with the first recording layer 26 and the second recording layer 28 with reference to FIG. 2 are incorporated herein.

The data storage device 80 further comprises a first protective layer 82 and a second protective layer 84. The first protective layer 82 is stacked adjacent to the first face 30a of the first recording layer 26 while the second protective layer 84 is stacked adjacent to the second recording layer 28 and interfacing the reflective layer 72 and the second recording layer 28. The first recording layer 26 and second recording layer 28 are disposed between and interfacing the first protective layer 82 and the second protective layer 84. Each of the first and second protective layers 82/84 is made from at least one of an oxide, a nitride, a chalcogenide element, fluoride and carbide of a metal.

Alternatively, each of the first and second protective layers 82/84 is a dielectric layer preferably made from at least one of SiO₂, SiO, Al₂O₃, GeO₂, In₂O₃, TeO₂, TiO₂, Ta₂O₅, MoO₃, WO₃, Si₃N₄, AlN, BN, TiN, ZnS, CdS, CdSe, ZnTe, AgF, PdF₂, SiC and mixtures thereof. The first protective layer 82 and the second protective layer 84

are to prevent the first recording layer 26 and the second recording layer 28 from corroding.

A fourth embodiment of the invention, a data storage device 90 as shown in FIG. 4, comprises five main elements: a substrate 22, a storage layer 24 having a first recording layer 26 and a second recording layer 28, a reflective layer 72, a first protective layer 82 and a second protective layer 84. The descriptions in relation to the structural configurations of and positional relationships between the substrate 22, the storage layer 24, the reflective layer 72, the first protective layer 82 and the second protective layer 84 and the first plurality of data storage locations 32a and the second plurality of data storage locations 32b corresponding with the first recording layer 26 and the second recording layer 28 with reference to the third embodiment of FIG. 3 are incorporated herein.

The storage layer 24 of the data storage device 90 further comprises an interface layer 92 stacked between the first recording layer 26 and the second recording layer 28. Preferably, the interface layer 92 is optically transparent to the laser beam 48 directed therethrough. The interface layer 92 is preferably made from one of a dielectric material and a metallic material being one of magnetic and non-magnetic. The interface layer 92 enables improved regulation and control of the second recording layer's temperature when the laser beam 48 is applied thereto during a data recording process where a minimum temperature has to be maintained by heat generated by the laser beam 48.

A fifth embodiment of the invention, a data storage device 100 as shown in FIG. 5, comprises five main elements: a substrate 22, a storage layer 24 having a first recording layer 26 and a second recording layer 28, a reflective layer 72, a first protective layer 82 and a second protective layer 84. The descriptions in relation to the structural configurations of and positional relationships between the storage layer 24, the reflective layer 72, the first protective layer 82 and the second protective layer 84 and the first plurality of data storage locations 32a and the second plurality of data storage locations 32b corresponding with the first recording layer 26 and the second

recording layer 28 with reference to the third embodiment of FIG. 3 are incorporated herein.

The substrate 22 of the third embodiment of the invention is replaced with a cover layer 102 stacked adjacent to the first face 30a of the first recording layer 26. In the fifth embodiment of the invention, the substrate 22 has been spatially altered and disposed over a face of the reflective layer 72 outwardly opposing the second protective layer 84. The reflective layer 72 is therefore stacked between the second protective layer 84 and the substrate 22.

The data storage device 100 in the fifth embodiment is preferably for a short wavelength laser light source, for example 405 nm violet-blue laser diode, is used for generating the laser beam 48. In the fifth embodiment, the laser beam transmits into data storage device 100 through the cover layer 102. The cover layer 102 is preferably made of at least one of polycarbonate, cellulose triacetate and polydicyclopentadiene, (methyl)methacrylate, and (methyl)propylacrylate and formed by one of solvent casting, polymerization-casting and die-coating methods. Additionally, the cover layer 102 is further formable by one of spin-coating followed by UV curing and lamination through application of a pressure-sensitive adhesive layer. Thickness of the cover layer 102 is preferably not more than 3 μm .

A sixth embodiment of the invention, a data storage device 120 as shown in FIG. 6, comprises seven main elements: a substrate 22, a storage layer 24 having a first recording layer 26 and a second recording layer 28, a reflective layer 72, a first protective layer 82, a second protective layer 84 and interface layer 92. The descriptions in relation to the structural configurations of and positional relationships between the storage layer 24, the reflective layer 72, the interface layer 92, the first protective layer 82 and the second protective layer 84 and the first plurality of data storage locations 32a and the second plurality of data storage locations 32b corresponding with the first recording layer 26 and the second recording layer 28 with reference to the fourth embodiment of FIG. 4 are incorporated herein.

The substrate 22 of the fourth embodiment of the invention is replaced with a cover layer 112 stacked adjacent to the first face 30a of the first recording layer 26. In the sixth embodiment of the invention, the substrate 22 has been spatially altered and disposed over a face of the reflective layer 72 outwardly opposing the second protective layer 84. The reflective layer 72 is therefore stacked between the second protective layer 84 and the substrate 22.

Similar to the data storage device 120 in the fifth embodiment, the data storage device 120 in the sixth embodiment is preferably also for a short wavelength laser light source, for example 405 nm violet-blue laser diode, is used as the laser beam 48. In the sixth embodiment, the laser beam transmits into data storage device 120 through the cover layer 112. The cover layer 112 is preferably made of at least one of polycarbonate, cellulose triacetate and polydicyclopentadiene, (methyl)methacrylate, and (methyl)propylacrylate and formed by one of solvent casting, polymerization-casting and die-coating methods. Additionally, the cover layer 112 is further formable by one of spin-coating followed by UV curing and lamination through application of a pressure-sensitive adhesive layer. Thickness of the cover layer 112 is preferably not more than 3 μm .

In the foregoing manner, a data storage device is described according to six embodiments of the invention for addressing the foregoing disadvantages of conventional data storage devices. Although only six embodiments of the invention are disclosed, it will be apparent to one skilled in the art in view of this disclosure that numerous changes and/or modification can be made without departing from the scope and spirit of the invention.

Claims

1. A data storage device comprising:

a first recording layer having a first face and a second face outwardly opposing the first face, the first recording layer having a first plurality of data storage locations, each of the first plurality of data storage locations having a first physical property being variable through at least two states for indicating a first data value;

a second recording layer stacked adjacent to the second face of the first recording layer, the second recording layer having a second plurality of data storage locations, each of the second plurality of data storage locations having a second physical property being variable through at least two states for indicating a second data value, the first physical property being distinct from the second physical property; and

a plurality of data axes formed substantially perpendicular to the second face of the first recording layer, each of the plurality of data axes extending through a corresponding one of the first plurality of data storage locations and a corresponding one of the second plurality of data storage locations,

wherein a processed beam having first and second beam properties is processed from a laser beam directed towards the first and second recording layers along one of the plurality of data axes, the laser beam being processed initially by the corresponding one of the first plurality of data storage locations with one of the at least two states thereof determining the first beam property, and subsequently by the corresponding one of the second plurality of data storage locations with one of the at least two states thereof determining the second beam property, the first and second beam properties of the processed beam being respectively indicative of the first and second data values of the corresponding one of the first plurality of data storage locations and the corresponding one of the second plurality of data storage locations.

2. The data storage device as in claim 1, the first physical property being reflectance and the second physical property being optical polarization,

wherein one of the at least two states of each of the first plurality of data storage locations corresponds with reflectance level thereof and one of the at least two states of each of the second plurality of data storage locations corresponds with optical polarization level thereof.

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3. The data storage device as in claim 1 or 2, the laser beam being directable initially towards the first recording layer and subsequently towards the second recording layer along one of the plurality of data axes for subsequently obtaining the processed beam therefrom.

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4. The data storage device as in any one of claims 1 to 3, the first recording layer being made from a first material and the second recording layer being made from a second material, the first material being one of different from and the same as the second material.

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5. The data storage device as in claim 4, the first material being a phase change material with the at least two states thereof being at least two crystallinity levels, and the second material being a magneto-optical material with the at least two states thereof being at least two polarization states.

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6. The data storage device as in claim 5, the first physical property of the first material being variable between a substantially crystalline state and a substantially amorphous state with the at least two crystallinity levels extending and forming graduations therebetween,

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wherein varying a portion of the first material between the substantially crystalline state and the substantially amorphous state varies at least one of reflectance and transmittance of the portion of the first material.

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7. The data storage device as in claim 5 or 6, the first physical property of the first material being variable by the laser beam having a magnitude, the magnitude of the laser beam corresponding to the at least two crystallinity levels.

8. The data storage device as in any one of claims 5 to 7, the second physical property of the second material being variable between two optical polarization levels with the at least two polarization states extending and forming graduations therebetween,

5 wherein varying the second physical property of a portion of the second material between the two optical polarization levels varies the at least two polarization states of the portion of the second material.

- 10 9. The data storage device as in any one of claims 5 to 8, the second physical property of the second material being variable by heat generated by the laser beam on the portion of the second material and a field direction of a magnetic field applied thereto.

- 15 10. The data storage device as in claim 9, the magnetic field being generated by one of a permanent magnet and an electromagnet.

- 20 11. The data storage device as in any one of claims 4 to 10, the first material being made from at least one element selected from at least one of Te, Ge, Sb, Te, Bi, Pd, Sn, As, Ag, In, Se, S, Si, P and organic recording materials.

12. The data storage device as in any one of claims 4 to 11, the second material being made from at least one of Fe, Co and Ni and at least one of Tb, Cr, Gd, Mn, Pt, Pd, Al, Au, Ag, Cu and Mg.

- 25 13. The data storage device as in any one of claims 4 to 12, each of the first recording layer and the second recording layer being formed by deposition of the corresponding one of the first material and the second material by one of vacuum deposition, electron beam vacuum deposition, ion plating, chemical vapor deposition, plasma CVD, laser deposition, spinning coating, molecular
30 beam epitaxy and sputtering.

14. The data storage device as in any one of claims 4 to 13, each of the first recording layer and the second recording layer being doped by sputtering of a mixture comprising Argon and at least one of Nitrogen and Oxygen thereto.

5 15. The data storage device as in any one of claims 1 to 14, further comprising:
a substrate for structurally supporting the first recording layer and the second recording layer, the first recording layer being stacked adjacent to the substrate with the first face thereof opposing the substrate.

10 16. The data storage device as in claim 15, the substrate being made from one of polycarbonate, polymethyl methacrylate (PMMA), amorphous polyolefin, ceramic and glass.

15 17. The data storage device as in any one of claims 1 to 14, further comprising:
a substrate for structurally supporting the first recording layer and the second recording layer, the second recording layer being stacked adjacent to the substrate and spatially disposed between the substrate and the first recording layer; and

20 a cover layer being stacked adjacent to the first recording layer with the first face thereof opposing the cover layer,

wherein the substrate is made from one of polycarbonate, polymethyl methacrylate (PMMA), amorphous polyolefin, ceramic and glass, and the cover layer is made from at least one of polycarbonate, cellulose triacetate and polydicyclopentadiene, (methyl)methacrylate and (methyl)propylacrylate.

25 18. The data storage device as in any one of claims 1 to 17, further comprising an interface layer stacked between the first recording layer and the second recording layer, the interface layer being optically transparent to the laser beam directed therethrough.

30 19. The data storage device as in claim 18, the interface layer being made from one of a dielectric material and a metallic material being one of magnetic and non-magnetic.

20. The data storage device as in any one of claims 1 to 19, further comprising:
a first protective layer stacked adjacent to the first face of the first recording layer; and
5 a second protective layer stacked adjacent to the second recording layer, the first and second recording layers being disposed between and stacked between the first protective layer and the second protective layer,
wherein each of the first and second protective layers is made from at least one of an oxide, a nitride, a chalcogenide element, fluoride and carbide of
10 a metal.
21. The data storage device as in claim 20, further comprising:
a reflective layer stacked adjacent to a face of the second protective layer outwardly opposing the second recording layer, the reflective layer for
15 dissipating excessive heat accumulation wherein heat is generated by the laser beam during application thereof to the second recording layer.
22. The data storage device as in any one of claims 1 to 19, further comprising:
a first dielectric layer stacked adjacent to the first face of the first recording layer; and
20 a second dielectric layer stacked adjacent to the second recording layer, the first and second recording layers being disposed between and stacked between the first dielectric layer and the second dielectric layer,
wherein each of the first and second dielectric layers is made from at
25 least one of SiO₂, SiO, Al₂O₃, GeO₂, In₂O₃, TeO₂, TiO₂, Ta₂O₅, MoO₃, WO₃, Si₃N₄, AlN, BN, TiN, ZnS, CdS, CdSe, ZnTe, AgF, PdF₂, SiC and mixtures thereof.
23. The data storage device as in claim 22, further comprising:
30 a reflective layer stacked adjacent to a face of the second dielectric layer outwardly opposing the second recording layer, the reflective layer for dissipating excessive heat accumulation wherein heat is generated by the laser beam during application thereof to the second recording layer

24. The data storage device as in any one of claims 1 to 19, further comprising:
a reflective layer stacked adjacent to a face of the second recording layer outwardly opposing the first recording layer, the reflective layer for
5 dissipating excessive heat accumulation wherein heat is generated by the laser beam during application thereof to the second recording layer.
25. The data storage device as in any one of claims 21, 23 and 24, the reflective layer being made from at least one of Au, Al, Ag, Ti, Cr, Cu, Pd, W and Pt.
- 10 26. The data storage device as in any one of claims 1 to 25, the first recording layer and the second storage being for storing at least two numerical bits of data.
- 15 27. The data storage device as in any one of claims 1 to 26, further comprising:
a plurality of magnitude ranges, the plurality of magnitude ranges being pre-defined and being associated with a first plurality of values comprising the first data value; and
a plurality of level ranges, the plurality of level ranges being pre-
20 defined and being associated with a second plurality of values comprising the second data value, the first and the second beam properties of the processed beam being respectively magnitude and optical polarization level thereof,
whereby detecting the magnitude and the optical polarization level of the processed beam and identifying one of the plurality of magnitude ranges
25 and one of the plurality of level ranges corresponding therewith enables the corresponding one of the plurality of first values and the corresponding one of the plurality of second values to be identified,
wherein the first data value and the second data value stored on
30 respectively the first recording layer and the second recording layer at one of the plurality of data storage locations of each thereof wherefrom the processed beam is reflected is obtained from the corresponding one of the plurality of first values and the corresponding one of the plurality of second values.

28. The data storage device as in any one of claims 1 to 27, data stored in the data storage device being obtained by applying one of an AND operator, an OR operator, a NAND operator and a NOR operator to the obtained first and second data values.

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29. A data storage device comprising:

a first recording layer having a first face and a second face outwardly opposing the first face, the first recording layer being made from a first material and having a first plurality of data storage locations, each of the first plurality of data storage locations having a first physical property being variable through at least two states for indicating a first data value;

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a second recording layer stacked adjacent to the second face of the first recording layer, the second recording layer being made from a second material and having a second plurality of data storage locations, each of the second plurality of data storage locations having a second physical property being variable through at least two states for indicating a second data value, the first physical property being distinct from the second physical property, wherein the first physical property is reflectance and the second physical property is optical polarization with one of the at least two states of each of the first plurality of data storage locations corresponding with reflectance level thereof and one of the at least two states of each of the second plurality of data storage locations corresponding with optical polarization level thereof, the first material being a phase change material with the at least two states thereof being at least two crystallinity levels, and the second material being a magneto-optical material with the at least two states thereof being at least two polarization states; and

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a plurality of data axes formed substantially perpendicular to the second face of the first recording layer, each of the plurality of data axes extending through a corresponding one of the first plurality of data storage locations and a corresponding one of the second plurality of data storage locations,

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wherein a processed beam having first and second beam properties is processed from a laser beam directed towards the first and second recording

layers along one of the plurality of data axes, the laser beam being processed initially by the corresponding one of the first plurality of data storage locations with one of the at least two states thereof determining the first beam property, and subsequently by the corresponding one of the second plurality of data storage locations with one of the at least two states thereof determining the second beam property, the first and second beam properties of the processed beam being respectively indicative of the first and second data values of the corresponding one of the first plurality of data storage locations and the corresponding one of the second plurality of data storage locations.

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30. The data storage device as in claim 29, the first physical property of the first material being variable between a substantially crystalline state and a substantially amorphous state with the at least two crystallinity levels extending and forming graduations therebetween,

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wherein varying a portion of the first material between the substantially crystalline state and the substantially amorphous state varies at least one of reflectance and transmittance of the portion of the first material,

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whereby the first physical property of the first material is variable by the laser beam having an magnitude, the magnitude of the laser beam corresponding to the at least two crystallinity levels.

31. The data storage device as in claim 29 or 30, the second physical property of the second material being variable between two optical polarization levels with the at least two polarization states extending and forming graduations therebetween,

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wherein varying the second physical property of a portion of the second material between the two optical polarization levels varies the at least two polarization states of the portion of the second material,

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whereby the second physical property of the second material is varied by heat generated by the laser beam on the portion of the second material and a field direction of a magnetic field applied thereto.

32. The data storage device as in claim 31, the magnetic field being generated by one of a permanent magnet or an electromagnet.
33. The data storage device as in any one of claims 29 to 32, the first material being made from at least one element selected from at least one of Te, Ge, Sb, Te, Bi, Pd, Sn, As, Ag, In, Se, S, Si, P and organic recording materials, and the second material being made from at least one of Fe, Co and Ni and at least one of Tb, Cr, Gd, Mn, Pt, Pd, Al, Au, Ag, Cu, Mg.
- ~~33~~ 34. The data storage device as in any one of claims 29 to 33, each of the first recording layer and the second recording layer being formed by deposition of the corresponding one of the first material and the second material by one of vacuum deposition, electron beam vacuum deposition, ion plating, chemical vapor deposition, plasma CVD, laser deposition, spinning coating, molecular beam epitaxy and sputtering.
35. The data storage device as in any one of claims 29 to 34, each of the first recording layer and the second recording layer being doped by sputtering of a mixture comprising Argon and at least one of Nitrogen and Oxygen thereto.
36. The data storage device as in any one of claims 29 to 35, further comprising:
a substrate for structurally supporting the first recording layer and the second recording layer, the first recording layer being stacked adjacent to the substrate with the first face thereof opposing the substrate.
37. The data storage device as in any one of claims 29 to 36, the substrate being made from one of polycarbonate, polymethyl methacrylate (PMMA), amorphous polyolefin, ceramic and glass.
38. The data storage device as in any one of claims 29 to 37, further comprising:
a reflective layer stacked adjacent to a face of the second recording layer outwardly opposing the first recording layer, the reflective layer for

dissipating excessive heat accumulation wherein heat is generated by the laser beam during application thereof to the second recording layer,

wherein the reflective layer is made from at least one of Au, Al, Ag, Ti, Cr, Cu, Pd, W and Pt.

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39. The data storage device as in any one of claims 29 to 38, further comprising:

a first protective layer stacked adjacent to the first face of the first recording layer, the first protective layer stacked between the substrate and the first recording layer; and

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a second protective layer stacked adjacent to the second recording layer, the first and second recording layer being disposed between and stacked between the first protective layer and the second protective layer;

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a reflective layer stacked adjacent to a face of the second protective layer outwardly opposing the second recording layer, the reflective layer for dissipating excessive heat accumulation wherein heat is generated by the laser beam during application thereof to the second recording layer,

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wherein each of the first and second protective layers is made from at least one of an oxide, a nitride, a chalcogenide element, fluoride or carbide of a metal, and the reflective layer is made from at least one of Au, Al, Ag, Ti, Cr, Cu, Pd, W and Pt.

40. The data storage device as in any one of claims 29 to 38, further comprising:

a first dielectric layer stacked adjacent to the first face of the first recording layer, the first protective layer stacked between the substrate and the first recording layer;

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a second dielectric layer stacked adjacent to the second recording layer, the first and second recording layer being disposed between and stacked between the first dielectric layer and the second dielectric layer; and

30

a reflective layer stacked adjacent to a face of the second dielectric layer outwardly opposing the second recording layer, the reflective layer for dissipating excessive heat accumulation wherein heat is generated by the laser beam during application thereof to the second recording layer,

wherein each of the first and second dielectric layers is made from at least one of SiO₂, SiO, Al₂O₃, GeO₂, In₂O₃, TeO₂, TiO₂, Ta₂O₅, MoO₃, WO₃, Si₃N₄, AlN, BN, TiN, ZnS, CdS, CdSe, ZnTe, AgF, PdF₂, SiC and mixtures thereof, and the reflective layer is made from at least one of Au, Al, Ag, Ti, Cr, Cu, Pd, W and Pt.

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41. The data storage device as in any one of claims 29 to 40, further comprising an interface layer stacked between the first recording layer and the second recording layer, the interface layer being optically transparent to the laser beam directed therethrough.

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42. The data storage device as in any one of claims 29 to 41, the interface layer being made from one of a dielectric material and a metallic material being one of magnetic and non-magnetic.

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43. The data storage device as in claim 29, further comprising:
a first dielectric layer stacked adjacent to the first face of the first recording layer, the first protective layer stacked between the substrate and the first recording layer;

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a second dielectric layer stacked adjacent to the second recording layer, the first and second recording layer being disposed between and stacked between the first dielectric layer and the second dielectric layer;

a reflective layer stacked adjacent to a face of the second dielectric layer outwardly opposing the second recording layer, the reflective layer for dissipating excessive heat accumulation wherein heat is generated by the laser beam during application thereof to the second recording layer;

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a cover layer being stacked adjacent to the first dielectric layer with the first dielectric layer stacked between the cover layer and the first recording layer; and

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a substrate for structurally supporting the first recording layer and the second recording layer, the reflective layer further being stacked adjacent to the substrate and stacked between the second dielectric layer and the substrate,

wherein each of the first and second dielectric layers is made from at least one of SiO₂, SiO, Al₂O₃, GeO₂, In₂O₃, TeO₂, TiO₂, Ta₂O₅, MoO₃, WO₃, Si₃N₄, AlN, BN, TiN, ZnS, CdS, CdSe, ZnTe, AgF, PdF₂, SiC and mixtures thereof, the reflective layer is made from at least one of Au, Al, Ag, Ti, Cr, Cu, Pd, W and Pt, the substrate being made from one of polycarbonate, polymethyl methacrylate (PMMA), amorphous polyolefin, ceramic and glass, and the cover layer is made from at least one of polycarbonate, cellulose triacetate and polydicyclopentadiene, (methyl)methacrylate and (methyl)propylacrylate.

44. The data storage device as in any one of claims 29 to 43, further comprising:
a plurality of magnitude ranges, the plurality of magnitude ranges being pre-defined and being associated with a first plurality of values comprising the first data value; and

a plurality of level ranges, the plurality of level ranges being pre-defined and being associated with a second plurality of values comprising the second data value, the first and the second beam properties of the processed beam being respectively magnitude and optical polarization level thereof,

whereby detecting the magnitude and the optical polarization level of the processed beam and identifying one of the plurality of magnitude ranges and one of the plurality of level ranges corresponding therewith enables the corresponding one of the plurality of first values and the corresponding one of the plurality of second values to be identified,

wherein the first data value and the second data value stored on respectively the first recording layer and the second recording layer at one of the plurality of data storage locations of each thereof wherefrom the processed beam is reflected is obtained from the corresponding one of the plurality of first values and the corresponding one of the plurality of second values.

45. The data storage device as in any one of claims 29 to 44, data stored in the data storage device is obtained by applying one of an AND operator, an OR operator, a NAND operator and a NOR operator to the obtained first and second data values.

46. A data storage device comprising:

5 a first recording layer having a first face and a second face outwardly opposing the first face, the first recording layer being made from a first material and having a first plurality of data storage locations, each of the first plurality of data storage locations having a first physical property being variable through at least two states for indicating a first data value;

10 a second recording layer stacked adjacent to the second face of the first recording layer, the second recording layer being made from a second material and having a second plurality of data storage locations, each of the second plurality of data storage locations having a second physical property being variable through at least two states for indicating a second data value, the first physical property being distinct from the second physical property, wherein the first physical property is optical polarization and the second physical property is reflectance with one of the at least two states of each of the first plurality of data storage locations corresponding with optical polarization level thereof and one of the at least two states of each of the second plurality of data storage locations corresponding with reflectance level thereof, the first material being a magneto-optical material with the at least two states thereof being at least two polarization states and the second material being a phase change material with the at least two states thereof being at least two crystallinity levels; and

15 a plurality of data axes formed substantially perpendicular to the second face of the first recording layer, each of the plurality of data axes extending through a corresponding one of the first plurality of data storage locations and a corresponding one of the second plurality of data storage locations,

20 wherein a processed beam having first and second beam properties is processed from a laser beam directed towards the first and second recording layers along one of the plurality of data axes, the laser beam being processed initially by the corresponding one of the first plurality of data storage locations with one of the at least two states thereof determining the first beam property, and subsequently by the corresponding one of the second plurality of data

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storage locations with one of the at least two states thereof determining the second beam property, the first and second beam properties of the processed beam being respectively indicative of the first and second data values of the corresponding one of the first plurality of data storage locations and the corresponding one of the second plurality of data storage locations.

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47. The data storage device as in claim 46, the first physical property of the first material being variable between two optical polarization levels with the at least two polarization states extending and forming graduations therebetween,

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wherein varying the first physical property of a portion of the first material between the two optical polarization levels varies the at least two polarization states of the portion of the first material,

whereby the first physical property of the first material being varied by heat generated by the laser beam on the portion of the first material and a field direction of a magnetic field applied thereto.

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48. The data storage device as in claim 47, the magnetic field being generated by one of a permanent magnet and an electromagnet.

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49. The data storage device as in any one of claims 46 to 48, the second physical property of the second material being variable between a substantially crystalline state and a substantially amorphous state with the at least two crystallinity levels extending and forming graduations therebetween,

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wherein varying a portion of the second material between the substantially crystalline state and the substantially amorphous state varies at least one of reflectance and transmittance of the portion of the second material,

whereby the second physical property of the second material is variable by the laser beam having an magnitude, the magnitude of the laser beam corresponding to the at least two crystallinity levels.

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A DATA STORAGE DEVICE

Abstract

5 A data storage device for providing multi-dimensional multi-level recording and storage is described according to embodiments of the invention. By providing multiple recording layers and property-variable data recording locations on each of the multiple recording layers, multi-dimensional and multi-level recording and storage are achieved. The property-variable locations enable the use of a single laser beam
10 without need for refocusing between recording layers as described and demonstrated by conventional data storage devices and methods. Therefore, recording density and data transfer rate of the data storage device are significantly increased.

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Figure 1