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(54) **THREE-DIMENSIONAL OPTICAL MEMORY**

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(57) **ABSTRACT**

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**Related U.S. Application Data**

(63) Continuation-in-part of application No. 10/240,420, filed on Jun. 12, 2003, now Pat. No. 7,011,925, which is a continuation-in-part of application No. 10/505,109, filed on May 25, 2005.

(30) **Foreign Application Priority Data**

Mar. 28, 2000 (IL) ..... 135309

The present invention is directed to a three-dimensional memory apparatus for storing information in a volume comprising of an active medium. The active medium is capable of changing from a first to a second isomeric form as a response to radiation of a light beam having an energy substantially equal to a first threshold energy. The concentration ratio between a first and a second isomeric form in any given volume portion represents a data unit. The active medium in the memory apparatus comprises of diarylalkene derivatives, triene derivatives, polyene derivatives or a mixture thereof. The invention is further directed to means for reading the data units from the isomeric states of the active medium in different portions of said active medium where the two isomeric forms have a substantially different absorption coefficient for absorbing energy of a second threshold energy. Reading may also be carried out by measuring the scattering pattern of the two isomeric forms.

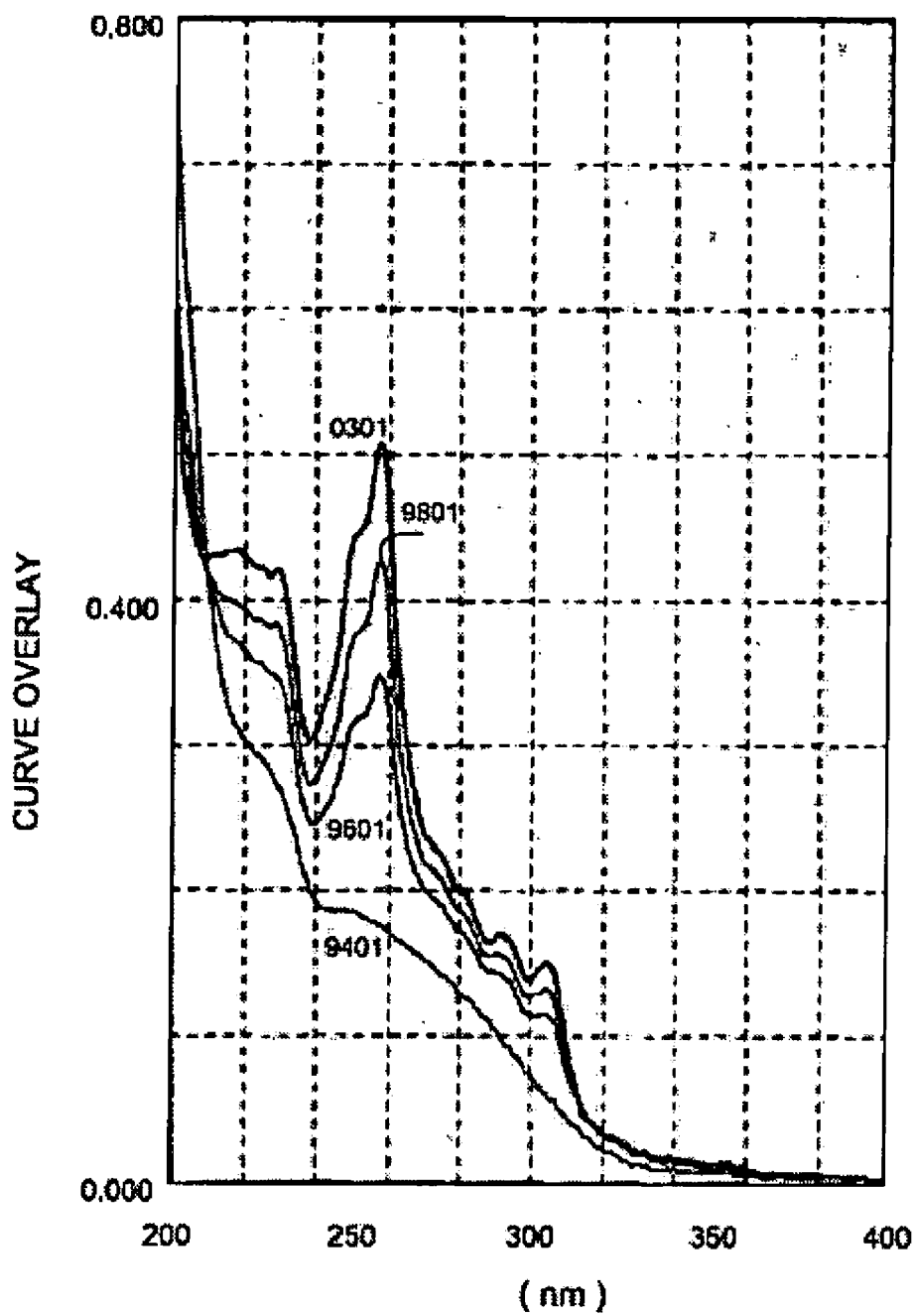


FIG. 1A

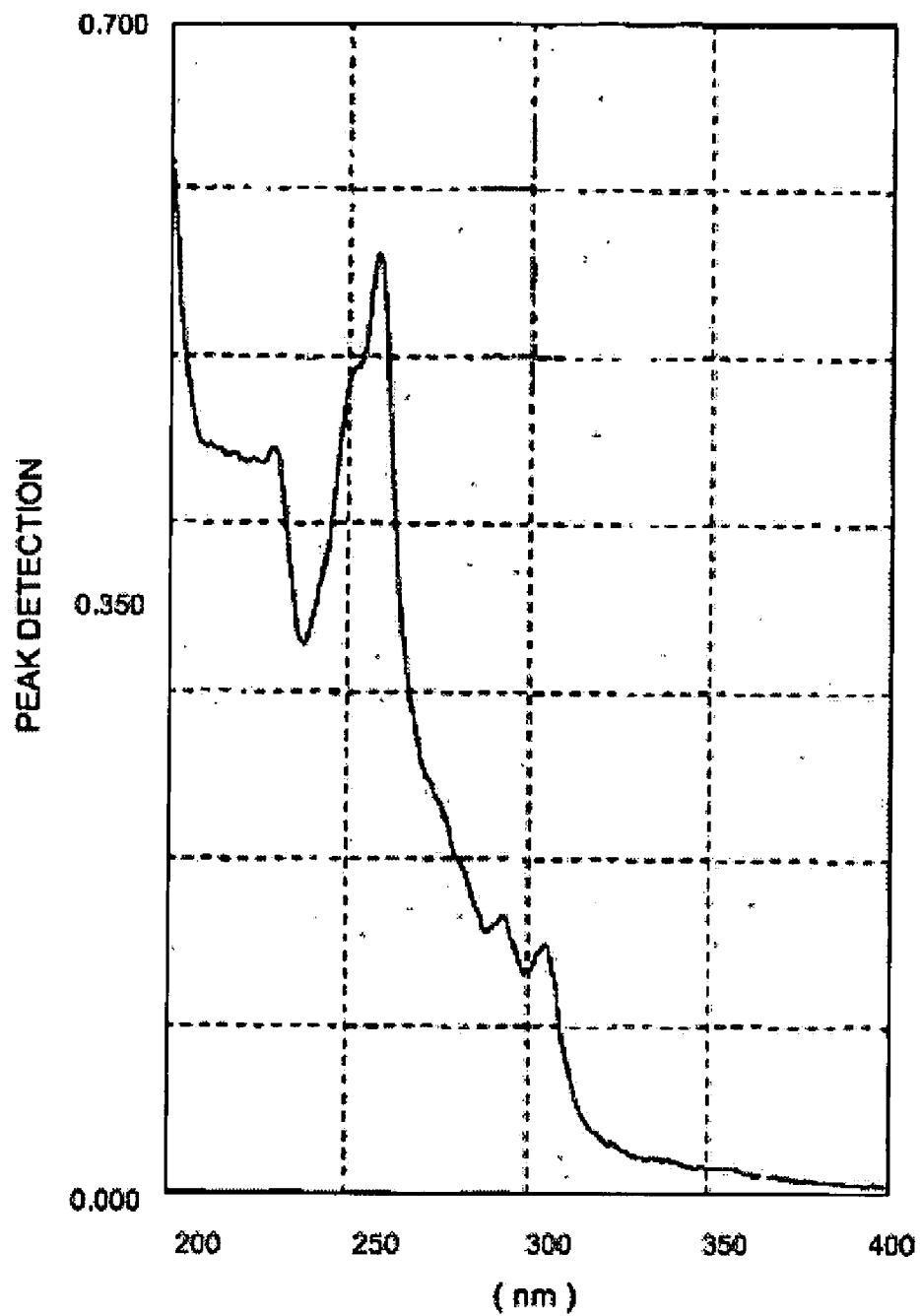


FIG 1R

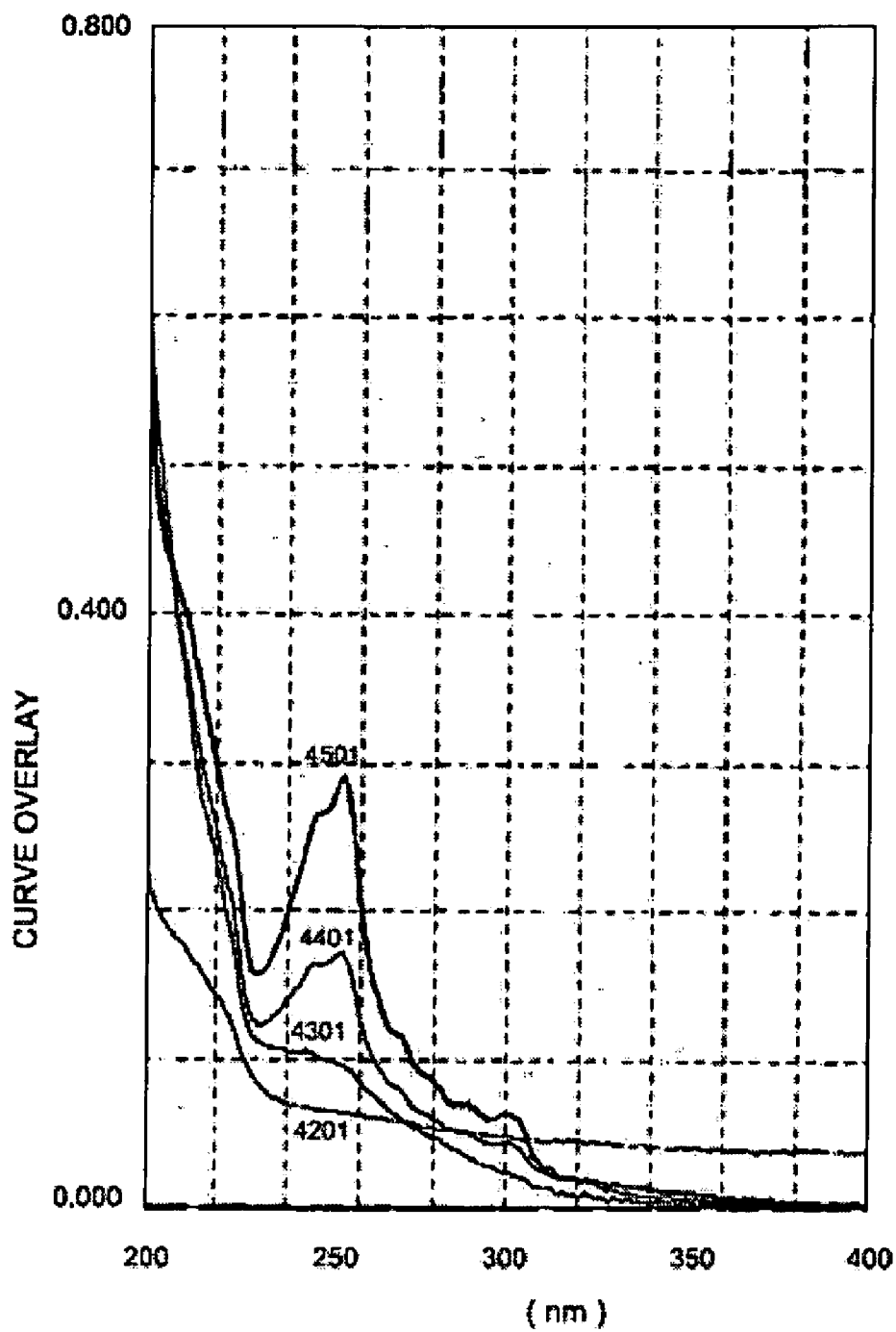


FIG 2A

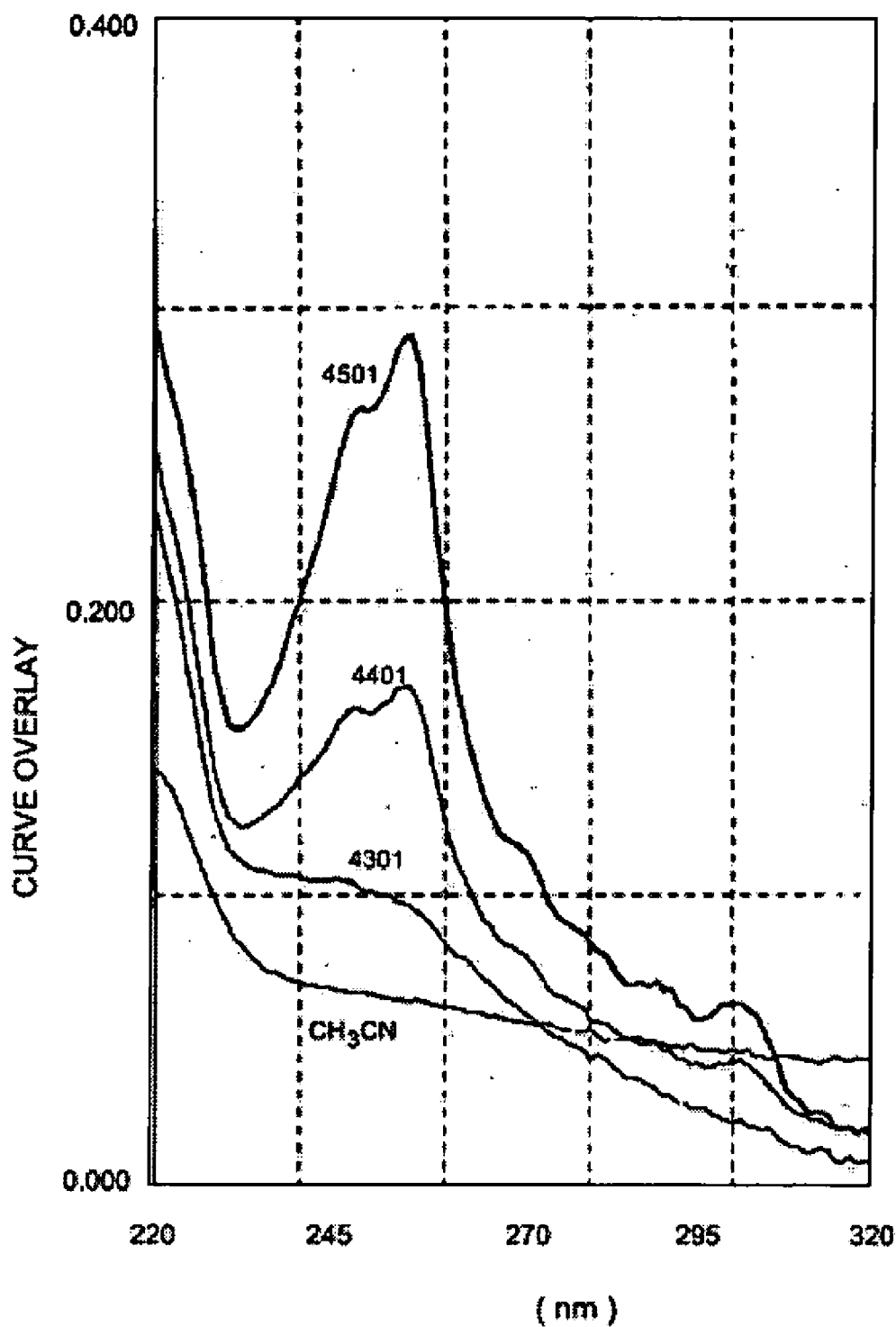


FIG 2R

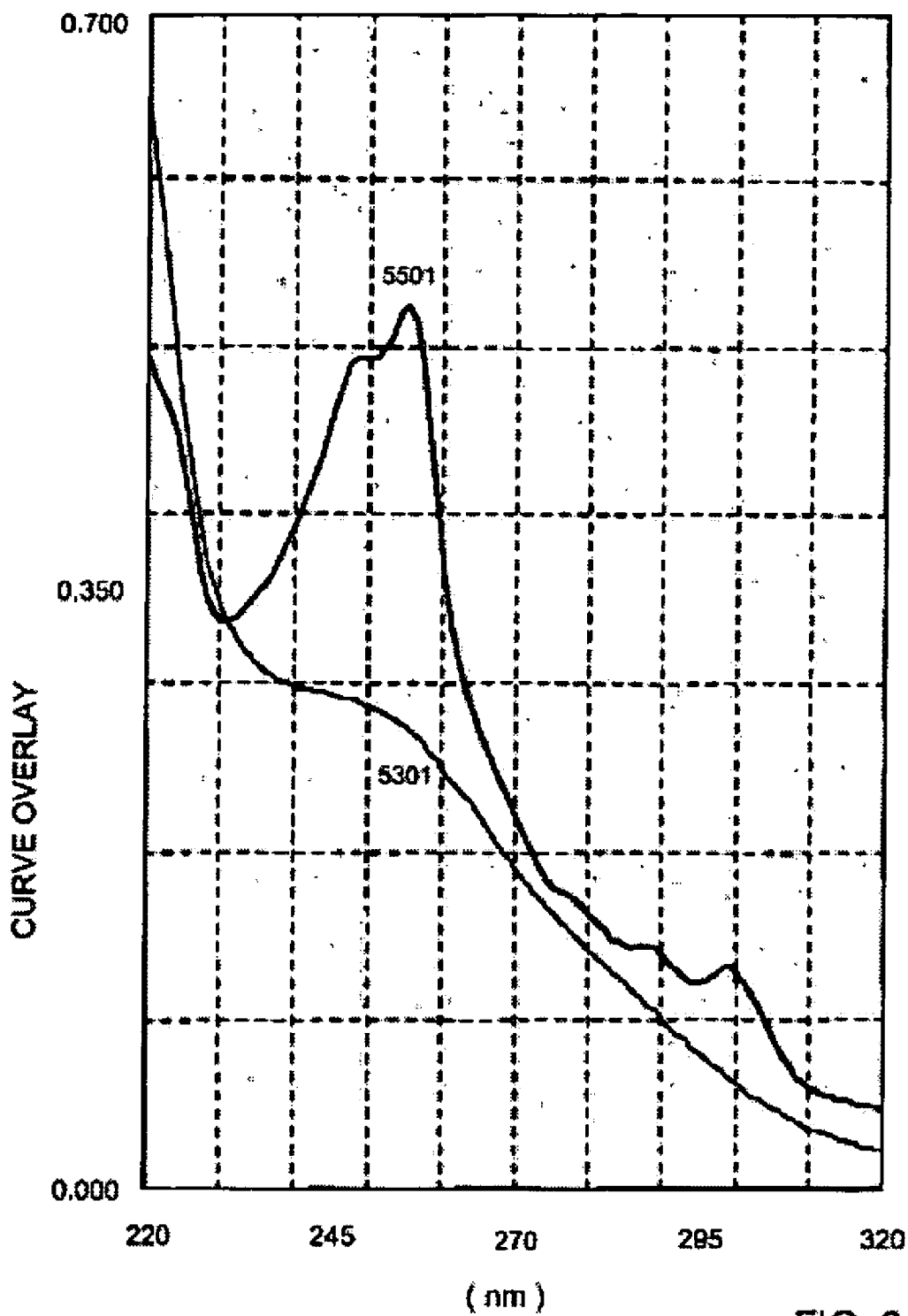


FIG. 3

Figure 4:

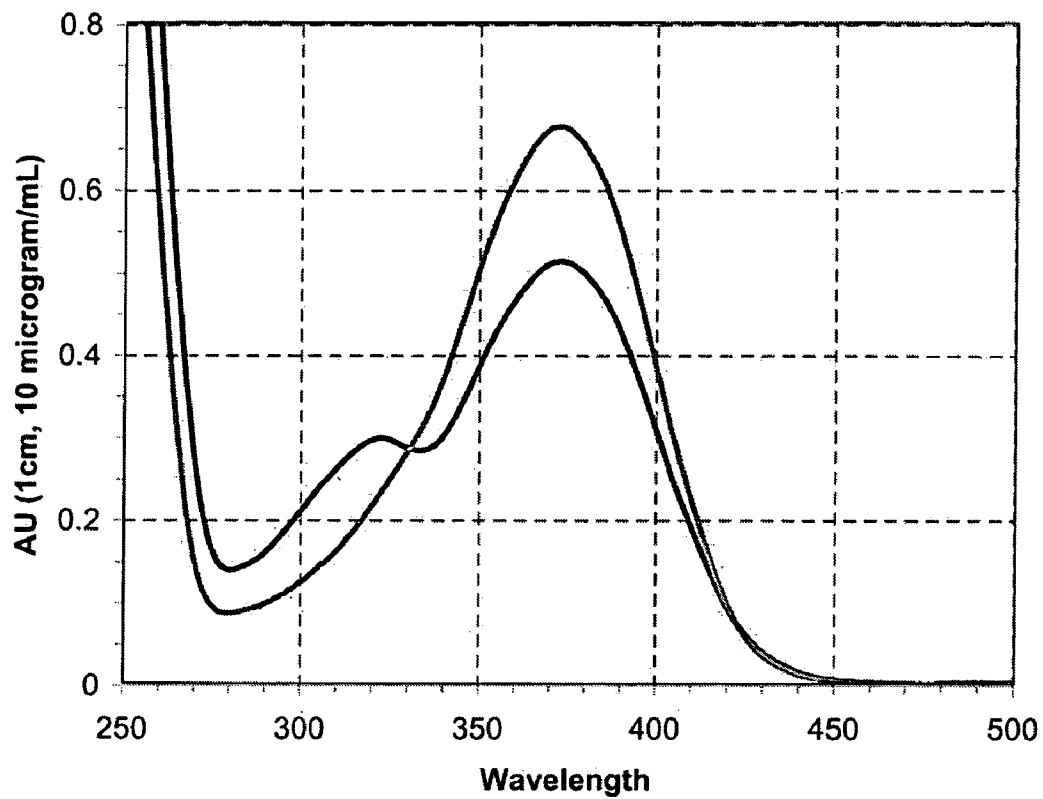


Figure 5:

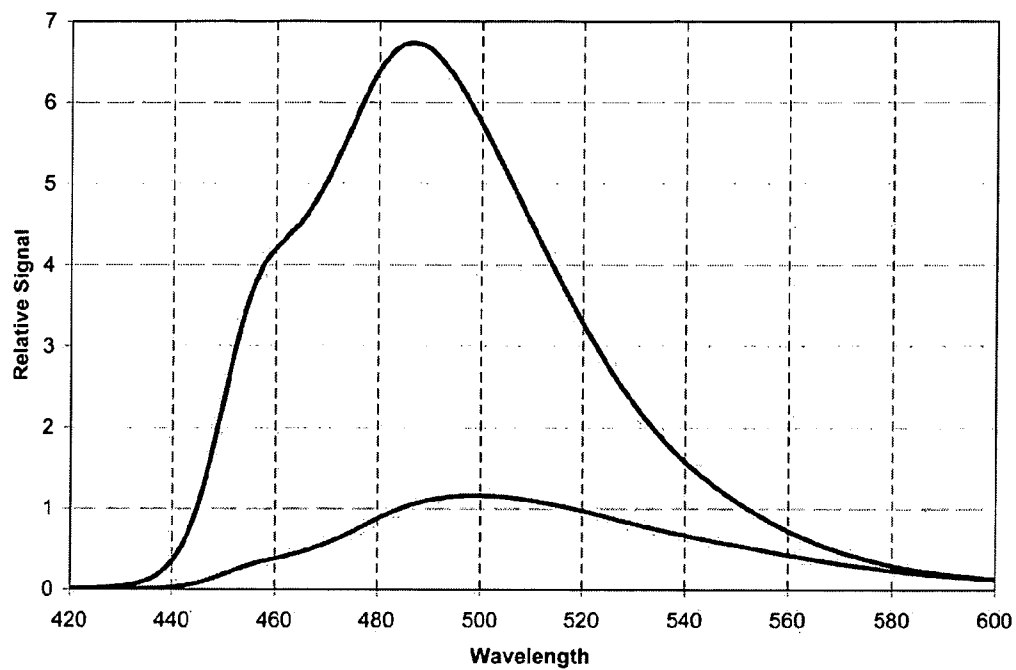


Figure 6:

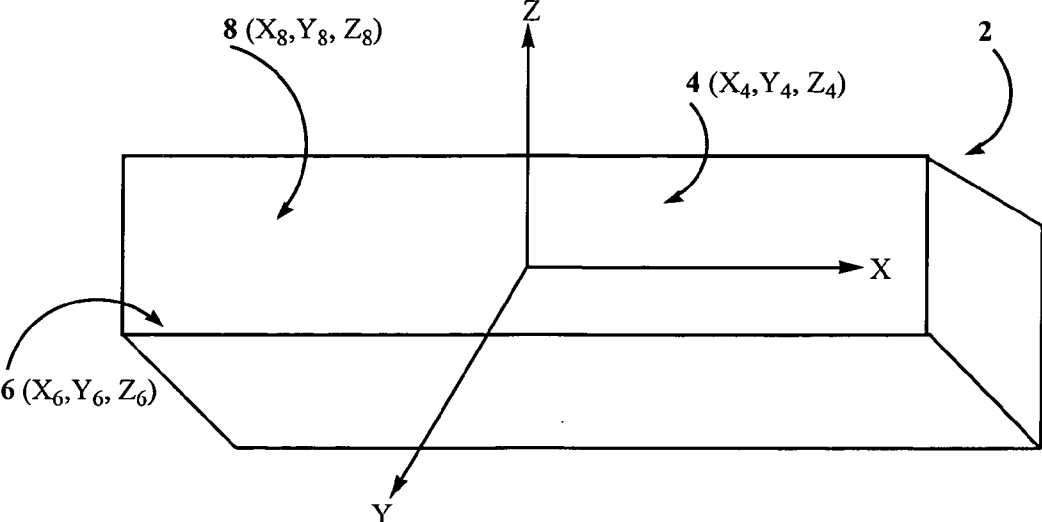


Figure 7:

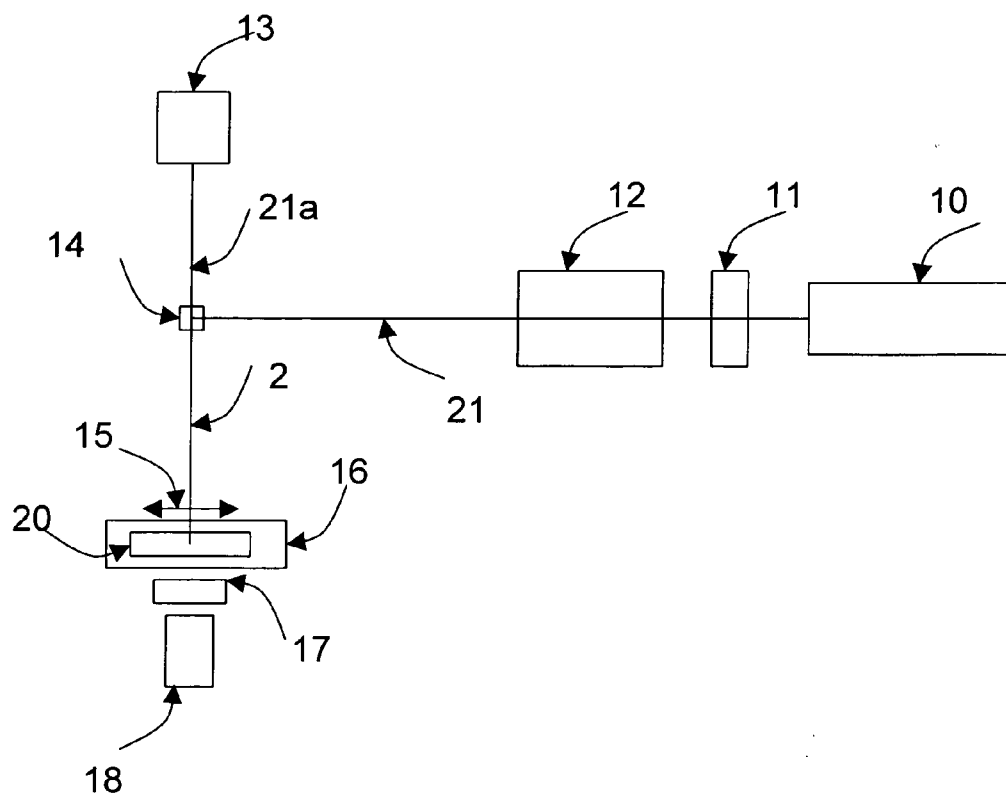


Figure 8:

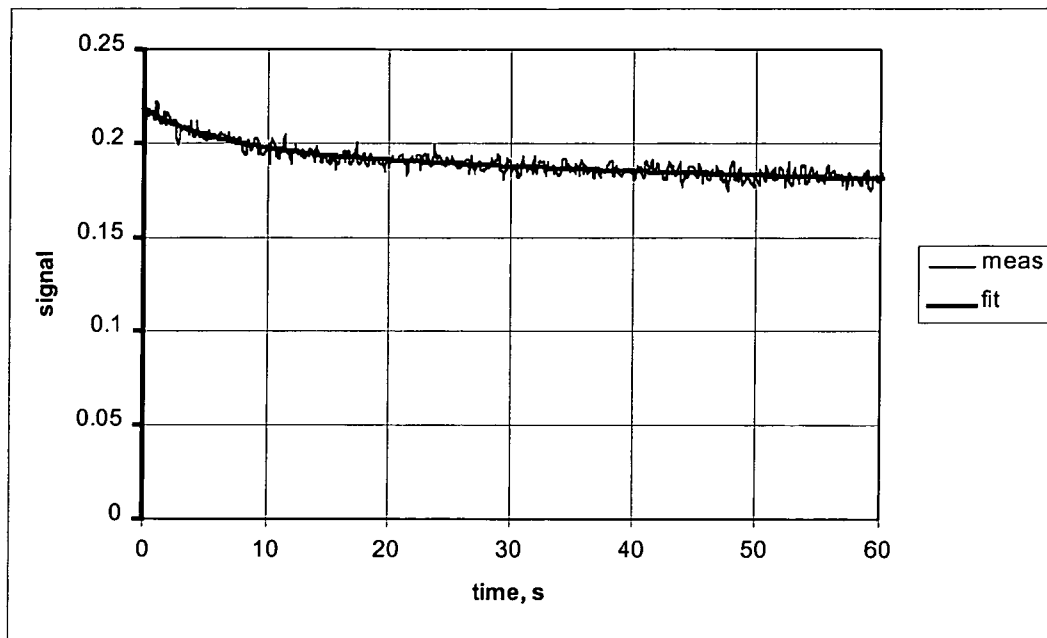
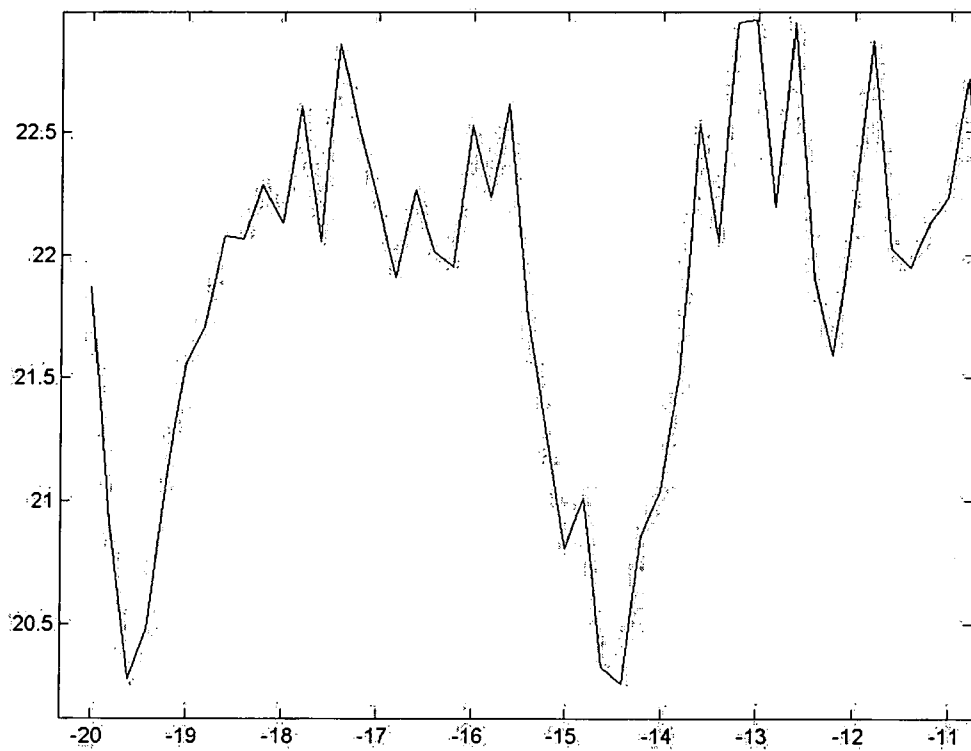


Figure 9:



### THREE-DIMENSIONAL OPTICAL MEMORY

[0001] This application is a continuation in part of U.S. application Ser. No. 10/240,420 dated Mar. 28, 2001 and continuation in part of U.S. application Ser. No. 10/505,109 dated Feb. 20, 2003 wherein these two applications are incorporated herein by reference.

#### FIELD OF THE INVENTION

[0002] This invention relates to a 3-dimensional optical data storage and retrieval system.

#### BACKGROUND OF THE INVENTION

[0003] The following publications are referred to in the present description:

[0004] 1) U.S. Pat. No. 5,592,462

[0005] 2) U.S. Pat. No. 5,268,862

[0006] The computerized era has raised the need to provide reliable means for storing large amounts of data. Ever-growing amounts of information are nowadays stored in personal and commercial computers, and with progress of technology, this demand will surely grow. One approach to fulfill such a need is to use optical methods for the storage of data, since an optical memory makes it feasible to pack information as binary digits at very high density. Furthermore, the stored information could be maintained undamaged for long periods of time, with no apparent loss of information.

[0007] U.S. Pat. No. 5,592,462 (Beldock) describes a three dimensional system for optical data storage and retrieval. According to this publication, incorporated herein as a reference, the data is stored and retrieved by irradiating the storage medium with two interfering light beams. The use of two light beams allows the definition of the particular portion of the volume being written or read at every instance.

[0008] U.S. Pat. No. 5,268,862 (Rentzepis) describes an active medium for use in a system of the kind describe by Beldock. The medium makes use of two forms of a spirobenzopyran derivative to represent the two binary digits. However, the memory is maintained at a temperature lower than room temperature, typically at  $-78^{\circ}\text{C}$ . Thus writing, storing the written information and reading is done at this low temperature. Raising the temperature will erase the entire stored information, as the active isomer is stable at room temperature for only 150 seconds. The maintenance of such a memory is expensive and cannot be used commercially.

[0009] There is thus a need for a low-cost, stable and efficient optical memory.

#### SUMMARY OF THE INVENTION

[0010] According to one aspect, the present invention provides a three-dimensional memory apparatus comprising an active medium, said active medium being capable of changing from a first to a second isomeric form in a multiphoton process; said memory apparatus being characterized in that said active medium comprises diarylalkene derivatives, substituted at least on the double bond. Preferably, one of said first and second isomeric forms is a cis form and the other one is a trans form.

[0011] The active medium of the present invention may be embedded in a supporting matrix, which may be a polymer, and the active medium is chemically bound thereto. In this respect the active medium itself may be a monomer that can be polymerized or co-polymerized to obtain the desired polymer three dimensional memory apparatus. In case the active medium is bound to a polymer, the active medium being capable of changing from a first isomeric form to another isomeric form in a multiphoton process. Hence an active medium according to the present invention should be understood as a plurality of molecules or active groups of polymers confined within a given volume that are capable of changing their states from one isomeric form to another wherein an isomeric state represents information.

[0012] The invention is further directed to a three-dimensional optical data carrier. This is an optical data carrier in the form of a solid disk comprising an active medium as defined above which is a removable object in the sense that it can be taken out and inserted upon desire in an appropriate three dimensional memory apparatus. The active medium of he optical data carrier may be embedded in a supporting matrix or chemically bound thereto such as being bound to a polymeric supporting matrix.

[0013] The information stored by the apparatus of the present invention is stored as a series of data units represented by the different isomeric forms residues. According to one embodiment, the data units are binary digits, and each portion of the active medium comprised in the volume represents a 0 or a 1. In this case, there is set a high concentration residue threshold and a low concentration residue threshold of the isomeric forms of the active medium. Volume portions having a concentration above the high ratio threshold represent 1 digit, while portions having a concentration below the low ratio threshold represent the other digit. For example, a volume portion having 70% or less active medium of the first isomeric form may represent 0, while a volume portion having 20% or less of active medium of the same isomeric form may represent 1. Alternatively, the data representation is analog, and each concentration represents a predefined data unit. Generally, the control of the different forms in a volume portion enables also other data encoding schemes that are well known in the art

[0014] Diarylalkene derivatives according to the present invention are of the general formula  $\text{Ar}_1\text{C}(\text{R}_1)=\text{C}(\text{R}_2)\text{Ar}_2$ , wherein  $\text{R}_1$  and  $\text{R}_2$  are not hydrogen and wherein  $\text{Ar}_1$  and  $\text{Ar}_2$  are optionally substituted aryl groups. In particular,  $\text{R}_1$  and  $\text{R}_2$  are electron acceptors which may be selected from pyridinium and ammonium salts, alkenyl or alkynyl groups, azobenzenes, nitrites, halides, carboxylic acids, derivatives thereof or their esters or nitro compounds. The substituents on the  $\text{Ar}_1$  and  $\text{Ar}_2$  are electron donors which may be selected from alkyls, alkoxy groups, ethers and thioethers, alcohols, thiols and their salts, amines, biphenyls, and heteroaromatics.

[0015] The three-dimensional memory apparatus according to the present invention may comprise a monolithic bulk (plate) or a single thin layer of active medium where the thickness allows only one data unit to be inscribed. The thickness of such a layer is determined by factors such as focusing and signal collection from such a layer. Typical focus size is less than 10 microns. Production capabilities

also dictate the layer thickness which is typically less than 50 microns, however can be also lower than 10 microns. A plurality of such thin layers of active medium as defined above where more than one data unit of information may be recorded and differentiated may also be produced. The active medium is capable of changing from a first to a second isomeric form in a multiphoton process. Such a three-dimensional memory apparatus is characterized in that its active medium comprises diarylalkene derivatives. In case the diarylalkene derivatives are bound to a polymer then the active medium is capable of changing from a first to another isomeric form in a multiphoton process.

[0016] Preferably, the apparatus according to the invention further comprises means for reading the data units from the isomeric forms of the active medium in different portions of said active medium.

[0017] Preferably, the isomeric form of a specific portion of the active medium is to be controlled (in the writing process) and determined (in the reading process) by directing towards the portion a light beam that interacts therein.

[0018] According to another of its aspects, the invention provides a method of producing a three-dimensional pattern of different response to multiphoton interaction

[0019] (a) providing a volume comprising an active medium, having diarylalkene derivatives and being capable of being in either a first or a second isomeric form, said medium being capable of changing from said first to said second isomeric form as a result of multiphoton absorption, and said first and second isomeric forms have mutually different response to multiphoton interaction;

[0020] (b) directing to selected portions of the active medium a light beam having only in said portion an intensity that activates multiphoton change of said active medium from the first to the second isomeric form, said selected portions having different X, Y, and Z coordinates;

thereby creating in said volume a three-dimensional pattern of different cross-sections to multiphoton absorption.

[0021] The invention is further directed to a method of producing a three-dimensional pattern of different response to multiphoton interaction:

[0022] (a) providing a volume comprising an active medium, having diarylalkene derivatives being capable of being in either a first or a second isomeric form, said medium being capable of changing from said first to said second isomeric form as a result of multiphoton absorption;

[0023] (b) transferring by nonlinear process to selected portions of the active medium a light energy having in said portion an energy threshold that activates change of said active medium from a first isomeric form, said selected portions having different X, Y, and Z coordinates.

[0024] According to yet another aspect, the present invention is directed to a method of identifying the isomeric form residue of an active medium in a portion of a three-dimensional pattern producible in a method as described

above. The method comprising directing to said portion of the pattern a light beam causing predominantly in said portion fluorescence, reading the intensity of the produced fluorescence, wherein said fluorescence being substantially different in intensity in one isomeric form than the other, and thereby identifying the isomeric form residue of the active medium in said portion.

[0025] According to yet another aspect, the present invention is directed to a method of identifying the isomeric form residue of an active medium comprising diarylalkenes in a portion of a three-dimensional pattern producible in a method as mentioned above, the method comprises directing to said portion of the pattern a light beam causing predominantly in said portion multiphoton interaction, and reading the intensity of the produced interaction

#### BRIEF DESCRIPTION OF THE DRAWINGS

[0026] In order to understand the invention and to see how it may be carried out in practice, a preferred embodiment will now be described, by way of non-limiting example only, with reference to the accompanying drawings, in which:

[0027] FIGS. 1A and 1B illustrate, respectively, a U.V. spectrum of a bulk of a trans substituted stilbene (diester) showing the formation of a photoproduct requiring isomerization to the cis isomer, and the spectrum of the formed photoproduct.

[0028] FIGS. 2A and 2B illustrate, respectively, a U.V. spectrum of a bulk of a trans substituted stilbene (dialcohol) showing the formation of a photoproduct that requires isomerization to the cis isomer, and the spectrum of the formed photoproduct.

[0029] FIG. 3 illustrates a U.V. spectrum of a bulk of a trans substituted stilbene (diester) showing the formation of the photoproduct.

[0030] FIG. 4 illustrates the U.V. spectra of the cis and trans forms of the compound of formula (II).

[0031] FIG. 5 illustrates the "read" signal of the cis and trans forms of the compound of formula (II).

[0032] FIG. 6 illustrates schematically an optical data carrier of the three dimensional memory apparatus comprising an active medium according to the invention.

[0033] FIG. 7 illustrates schematically a system for recording and reading of information from a 3-dimensional memory apparatus according to the present invention.

[0034] FIG. 8 illustrates a process of recording a mark in a 3D optical disk according to the invention with many pulses. The recording was performed with simultaneous reading of the recorded mark using a set up schematically described by FIG. 7.

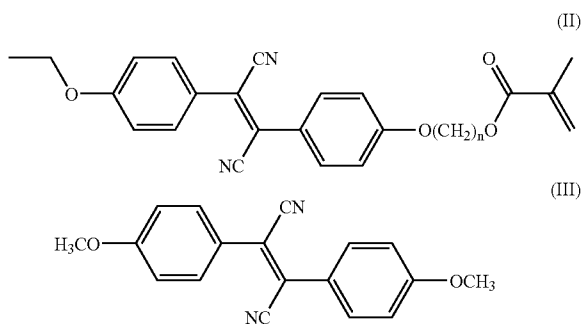
[0035] FIG. 9 illustrates a process of recording a mark in a 3D optical disk according to the invention with a single pulse. The recording was performed with simultaneous reading of the recorded mark using a set up schematically described by FIG. 7.

#### DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

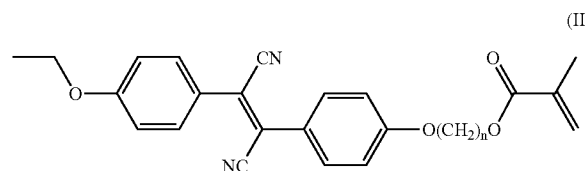
[0036] As mentioned the present invention concerns a three-dimensional memory apparatus whose active medium

is comprised of a diarylalkene derivative that is capable of changing from a first to a second isomeric form in a multiphoton process. Diarylalkene derivatives according to the present invention are of the general formula  $Ar_1C(R_1)=C(R_2)Ar_2$ , wherein  $Ar_1$  and  $Ar_2$  which could be the same or different, are independently substituted or non-substituted aryl groups. If they are substituted, they are preferably substituted with electron donors. Non limiting examples of electron donors are alkyls, alkoxy groups, ethers and thioethers, alcohols, thiols and their salts, amines, biphenyls, and heteroaromatics.  $R_1$  and  $R_2$  which are the same or different, are not hydrogen, and are preferable electron acceptors. Non limiting examples of electron acceptors are pyridinium and ammonium salts, alkenyl or alkynyl groups, azobenzenes, nitriles, halides, carboxylic acids, derivatives thereof or their esters or nitro compounds. More specifically,  $R_1$  and  $R_2$  are nitriles,  $C_{1-8}\beta$ -carboxylic acids or their esters, 2-hydroxy $C_{1-8}$ alkyl, 2-fluoroxy $C_{1-8}$ alkyl, 2-nitro $C_{1-8}$ alkyl, 2-cyano $C_{1-8}$ alkyl or a nitro group. Most preferably the substituents on the aryl rings are  $C_{1-4}$  lower alkyls or  $O-C_{1-4}$  alkyls and the  $R_1$  and  $R_2$  are chosen from cyano. The use of such diarylalkene, derivatives or mixtures thereof allows the memory apparatus of the invention to be fully operative in room temperature, due to the great thermal stability of each of their isomeric forms. The two isomeric states of the diarylalkene are stable for long periods of time, and essentially no spontaneous thermally induced inter-conversion of one isomeric form to the other occurs. This stability further enables the memory apparatus to be of a kind that may be written and read many times, e.g. it may be a rewritable memory as well as a WORM (=Write Once Read Many).

[0037] FIGS. 1-3 illustrate the ultra violet spectrum of various trans diarylalkenes which may serve as the active medium of the 3-dimensional memory apparatus according to the present invention (trans-4-bromostilbene diethylacetate trans-stilbene dipropylol trans-stilbene diethylacetate, respectively). These figures demonstrate the formation of the cis isomer upon irradiation of the trans compound. Hence in these figures the cis and trans isomers each represents a different form of residue. Hence in an active medium of a three dimensional memory apparatus consisting of one of the three substituted stilbenes (FIGS. 1-3), upon the interaction of the active medium with a light beam, selected portions of a memory apparatus may be in either residue form (cis and trans in the present case). By way of illustration, an active medium according to the present invention may be a chemical of formula (II) or (III):



[0038] The compound of formula (III) is a diarylalkene having electron acceptors on the double bond and electron donors substituents on the two aryl groups, that serves as an active medium. The compound of formula (II) is an example of a compound of the active medium which already comprises a part rendering the compound a monomer. It is a diarylalkene having electron acceptors on the double bond and electron donors substituents on the two aryl groups, that serves as an active medium. It is further bound through a spacer to a polymerizable group turning the active medium into a monomer that can be polymerized into a polymer. Turning to FIG. 4 there is illustrated the ultra violet spectrum of both the cis and trans forms of a compound of formula (II):



[0039] The cis and trans isomers of the compound of formula (II) were found to be stable to visible light and I.R. irradiation and further to isomerizes by bi-photon process. As may be seen in FIG. 4, the cis and trans forms of compound (II) have very similar linear spectra. Hence, these two forms have almost no difference in their refractive index. Once incorporated into the disk, e.g. by polymerization, the cis and trans forms of the compound maintain their spectra leading to essentially no change in the single photon refractive index between recorded volume and unrecorded volume. Turning to FIG. 5 there is illustrated the possibility of data retrieval, i.e. signal reading, which is possible due to the fact that there exists a significant difference between the signals of the cis and trans forms of compound (II). The signal from the first isomeric form is much larger than the signal from the second isomeric form. The signal obtained from the interrogated portion of the medium is also factored by the cross-section to absorption. In case the cross-section to absorption of the first isomeric form is larger than that of the second isomeric form, then the signal ratio would be much larger. Consequently, the signal can be thought of as measuring the residue of the first isomeric form. FIG. 6 is a schematic illustration of a three-dimensional optical data carrier 2 in accordance with one embodiment of the invention. This is an optical data carrier in the form of a solid disk, and is three-dimensional in the sense that data may be recorded anywhere within the bulk of the disk 2, for instance at voxels 4 and 6, that have coordinates  $(x_4, y_4, z_4)$ , and  $(x_6, y_6, z_6)$ , respectively wherein  $x_4 \neq x_6$ ,  $y_4 \neq y_6$ , and  $z_4 \neq z_6$ . In particular, storage is not limited to any specific plane in the apparatus 2. In three dimensional optical data storage of this kind, light that reaches a specific voxel i.e. 6 may travel on its way to this voxel through other voxels i.e. 8 (having coordinates  $X_8, Y_8, Z_8$ ). In order to optically read or write voxel 6, without interrupting voxel 8, the present invention uses multiphoton optical phenomena, such that only one voxel undergoes predominant multiphoton interaction while being read or written. For this, the apparatus 2 comprises an active medium, which is capable of changing from a cis isomeric form to a trans isomeric form or from trans to cis

as a response to a multiphoton process. It should be understood that the optical data carrier is a removable object that can be inserted in the appropriate three dimensional apparatus, data may be recorded and/or read and later the data carrier can be taken out upon desire and reinserted into another three dimensional apparatus for further recording and/or reading.

[0040] The optical data carrier apparatus is linearly transparent to the multiphoton interacting light; hence such interaction does not interfere with recording or retrieving of information. It should be understood that as indicated by quantum selection rules, the linear optical reaction of the first and second isomeric forms to irradiation is different than their multi-photon interaction with irradiation, e.g. by exposing the medium to irradiation suitable for bi-photon interaction one obtains interactions which are not achievable with single photon interaction. Thus the multiphoton process according to the present invention may be two-photon excitation and subsequent fluorescence or it may be a different form of non-linear interaction such as one of the family of four wave mixing interaction or different forms of Raman scattering detection. The concentration of the isomeric forms in a given volume portion represents a data unit. Hence according to the present invention one may utilize the 3D optical memory to record a 3D mark in the volume and retrieve it. Once the method of recording such marks and retrieving information about their isomeric form is given, there are numerous techniques to encode data which are well known in the art. Turning to FIG. 7, there is illustrated in a schematic manner a system that is used for the recording and retrieving of data from a three dimensional optical memory in testing conditions, the system can be adapted by a person skilled in the art to store data in three dimensions in a rotating disk in multi-virtual layers as disclosed in PCT/IL04/00730 ("Method and apparatus for formatting and tracking information for three dimensional storage medium"). The system is equipped with a solid state laser irradiating at 671 nm at **10**, used for testing the media, with an acousto-optical modulator **11**, with a beam expander **12**, an OPU **13** which is an integrated laser diode, collimating and laser driving module, a non-polarizing beam splitter at **14**, a focusing lens system **15**, a disk holder **16** positioned on an actuator (not shown), a wavelength filter **17** a photo detector **18** (e.g. photo multiplier (PMT), Avalanche photodiode (APD) or PIN diode), and a disk **20**. The upper branch beam coming from the laser diode module **13** is represented by **21a**. The right branch beam coming from the solid state laser **10** is represented by **21b**. **22** represents the beam going to the focusing lens system **15** which may be originating from either the upper or the right branch **21a** or **21b**, respectively. It should be understood that the right branch of the scheme, **10-12** including the resulting beam **21b** is redundant to upper branch **13** and beam **21a**. The different branches merely serve to test data recording and retrieving in different conditions (pulse power, duration etc) where one of the branches need not be present in operative conditions. A chromatic corrected and spherical aberration corrected lens system at **15** allows the mutual focusing of different wavelengths to the same locations in a large depth range as disclosed in PCT/IL03/00803. The OPU **13** comprises at least one laser diode (where two laser diodes in the OPU are superimposed into one beam), at least one driver for the diodes, collimation or semi collimation for each diode. In this set up the OPU is designed to provide a collimated beam

of controlled width. The width of the beam controls the amount of overfilling or under filling of the lens system, which in turn controls the effective NA of the focusing system and its energetic efficiency. Other methods such as the transformation of a Gaussian beam to a uniform beam are also known in the art. The control of width of the beam in this setup is shown for the right branch, where a beam expander **12** is used. An acousto-optic modulator **11** allows external modulation of the pulse stream. Alternatively the pulse stream from the OPU is electronically controlled.

[0041] The alternative beams **21a** and **21b** are combined into one beam by a non-polarizing beam splitter **14** and directed into the focusing system. In a first embodiment the focusing lens is a standard DVD lens (NA=0.65) which is SA corrected for approximately 100 microns around the depth of 0.6 mm. In a second embodiment a lens system that is both chromatically corrected and corrected for spherical aberrations is used. Such for example is the Olympus LCPlanFI lens. If additional requirements are applied such as the control of the distance between the foci of different wavelengths and low weight then a lens system disclosed in PCT/IL03/00803 may be used. It should be noted that according to the present invention one may record a mark and continuously obtain a signal in a 3D optical disk in a many pulse sequence or only record a mark with a one pulse (Examples 5 and 6, respectively). The energy in the reading performed with the reading performed with the continuous recording (many pulse sequence—Example 5) is different than the energy in the recording without reading (one pulse—Example 6) clearly demonstrating that there are two threshold energies.

[0042] Data recording is a non linear process performed with one beam. The process is a multi-photon process of absorbance of photons having a first energy threshold. In a preferred embodiment, data retrieval (reading the recorded data) is also a two photon process done with one beam.

[0043] In a preferred embodiment of the invention, the isomeric forms of the active medium have a substantially different absorption coefficient for absorbing energy of second threshold energy, thus allowing the retrieval of the information in a manner similar to its preferred manner of writing, described below.

[0044] The substituents on the various double bonds determine in part the I.R. spectrum and the Raman scattering pattern of each of the possible isomeric forms of the active medium. The I.R. spectra and the Raman scattering of the substituents will be significantly different in each of the different isomeric forms of the diarylalkene derivatives (bound or non-bound to the polymer). The Raman scattering may be detected by Coherence Anti-Stokes Raman Spectroscopy (CARS), by Raman Induced Kerr Effect Spectroscopy (RIKES) or a variation thereof.

## EXAMPLES

### Example 1

[0045] Pure trans-4-bromostilbene diethylacetate was dissolved in acetonitrile and irradiated with a mercury lamp having a Hg filter. The U.V. spectrum displayed in FIG. 1A illustrates the spectrum of the pure trans isomer (designated 9401). The cis isomer leads to a photoproduct that has a strong absorption at 254 nm, and thus also shown are the

resulting spectrum of the formed mixture of compounds after 5 minutes of irradiation (designated 9601), the resulting spectrum of the formed mixture of compounds after 8 minutes of irradiation (designated 9801) and the resulting spectrum of the formed mixture of compounds after 15 minutes of irradiation (designated 0301). FIG. 1B illustrates the spectrum of the residue after 18 hrs of irradiation.

#### Example 2

[0046] Pure trans-stilbene dipropanol was dissolved in acetonitrile and irradiated with a mercury lamp having a Hg filter. The U.V. spectrum displayed in FIG. 2A illustrates the spectrum of the pure trans isomer (designated 4301), the resulting spectrum of the formed mixture of trans and cis isomers (having a strong absorption at 254 nm) after 2 minutes of irradiation (designated 4401), the resulting spectrum of the formed mixture of trans and cis isomers after 6 minutes of irradiation (designated 4501). The spectrum of the acetonitrile is designated 4201. FIG. 2B illustrates the spectrum of the cis-stilbene dipropanol as in FIG. 2A, however after the abstraction of the acetonitrile spectrum.

#### Example 3

[0047] trans-stilbene diethylacetate was dissolved in acetonitrile and irradiated with a mercury lamp having a Hg filter. The displayed U.V. spectrum (FIG. 3) illustrates the spectrum of the pure trans isomer (designated 5301), and the resulting spectrum of the formed residue (with the photo-product arising from the cis-isomer having a strong absorption at 254 nm) after 22 hrs of irradiation (designated 5501)

#### Example 4

[0048] Manufacturing of a 3-dimensional memory apparatus comprising as the active medium a compound of formula (II). A mixture of methyl methacrylate, (89.03% w/w), an radical initiator 2,2'-azobis(isobutyronitrile) (0.97% w/w) and a compound of formula (III, n=3) (10.0% w/w) are stirred at 65° C. for 60 minutes where the polymerization is initiated. The mixture is then filtered, degassed and filled into a mold. Polymerization continues at 65° C. for 24 hours after which a translucent monolithic bulk is obtained. The bulk is a polymer that comprises photoactive pendant groups that are highly susceptible to interaction with light.

#### Example 5

[0049] Recording a mark and obtaining a signal with many pulses in a 3D optical disk.

[0050] An acrylate based disk having as its active medium 10% weight of a compound of formula II was used. FIG. 8 displays the process of recording a mark in such a disk where the recording was performed with simultaneous reading of the recorded mark using a set up schematically described by FIG. 7. The disk was irradiated with light from a standard DVD laser diode driven at low pulse frequency (20 KHz) with peak power of 330 mW and with pulse duration of about 18 ns and is focused into the disk with NA of about 0.7. Emitted light is collected with a PMT (Hamamatsu R74004) and the signal is detected using a lock-in amplifier (Stanford-research SR850 DSP). Detected signal is averaged by the lock-in amplifier with integration

time of 30 ms. FIG. 8 shows a controlled recording process allows continuous control of the isomers concentration in a selected portion of the disk.

#### Example 6

[0051] Recording a mark with one pulse in a 3D optical disk. An acrylate based disk having as its active medium 10% weight of a compound of formula II was used. FIG. 9 displays a scan of a recorded mark in such a disk where the recording was performed with one pulse from a 671 nm laser (peak power 100W, pulse duration 17 ns) using a set up schematically described by FIG. 7. For the read scan the disk was irradiated with light from a standard DVD laser diode as schematically described by the upper branch 21a of FIG. 7. Emitted light is detected with a PMT and the signal is detected using a Box-car detector (Stanford-research SR280). The scan of the focus point is performed by actuating the disk relative to the fixed optical set up. FIG. 9 shows a controlled recording and reading process that allows control of the isomers ratio in a selected portion of the disk that is localized to less than 2 microns in the direction orthogonal to the optical axis. Similar localization is found in the optical axis direction.

[0052] The signal from the mark is lower than the signal from the surrounding volume. The modulation depth of the recorded mark formally is defined as

$$M = \frac{P_{MAX} - P_{MIN}}{P_{MAX}}$$

where  $P_{max}$  is the signal from space (pointed out by the dotted line) and  $P_{min}$  is the signal from a mark (pointed by a circle). The modulation of recorded mark in this example is about 8%.

1. A three-dimensional memory apparatus comprising an active medium, said active medium being capable of changing from a first to a second isomeric form in a multiphoton process; said memory apparatus being characterized in that said active medium comprises diarylalkene derivatives of formula (I):



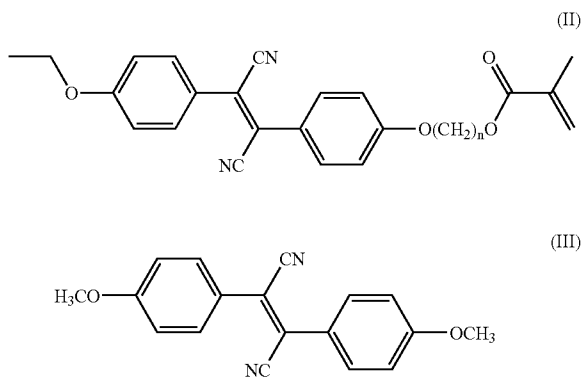
wherein  $R_1$  and  $R_2$  are not hydrogen and wherein  $Ar_1$  and  $Ar_2$  are optionally substituted aryl groups.

2. A three-dimensional memory apparatus according to claim 1, wherein one of said first and second isomeric forms is a cis form and the other one is a trans form.

3. A three-dimensional memory apparatus according to claim 1 which is linearly transparent to interacting light.

4. A three-dimensional memory apparatus according to claim 1, wherein  $R_1$  and  $R_2$  are electron acceptors selected from pyridinium and ammonium salts, alkenyl or alkynyl groups, azobenzenes, nitrites, halides, or nitro compounds and the substituents on the  $Ar_1$  and  $Ar_2$  are electron donors selected from alkyls, alkoxy groups, ethers and thioethers, alcohols, thiols and their salts, amines, biphenyls, and heteroaromatics.

5. A three-dimensional memory apparatus according to claim 4, wherein the active medium is a compound of formula (II) or (III):



wherein n is 1 to 6.

6. An optical data carrier comprising an active medium, said active medium being capable of changing from a first to a second isomeric form in a multiphoton process; said optical data carrier being characterized in that said active medium comprises diarylalkene derivatives.

7. An optical data carrier according to claim 6, wherein one of said first and second isomeric forms is a cis form and the other one is a trans form.

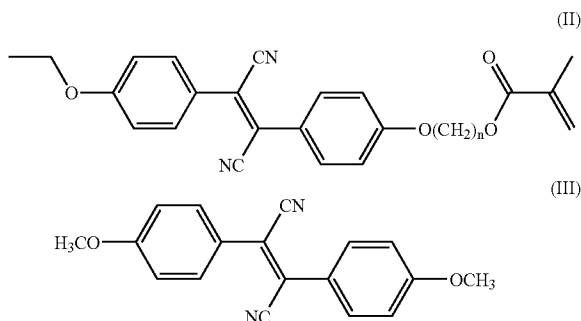
8. An optical data carrier according to claim 6, wherein said diarylalkene derivatives are of the general formula



wherein  $\text{R}_1$  and  $\text{R}_2$  are not hydrogen and wherein  $\text{Ar}_1$  and  $\text{Ar}_2$  are optionally substituted aryl groups.

9. An optical data carrier according to claim 6, wherein  $\text{R}_1$  and  $\text{R}_2$  are electron acceptors selected from pyridinium and ammonium salts, alkenyl or alkynyl groups, azobenzenes, nitrites, halides, or nitro compounds and the substituents on the  $\text{Ar}_1$  and  $\text{Ar}_2$  are electron donors selected from alkyls, alkoxy groups, ethers and thioethers, alcohols, thiols and their salts, amines, biphenyls, and heteroaromatics.

10. An optical data carrier according to claim 9 wherein the active medium is a compound of formula (II) or (III):



wherein n is 1 to 6.

11. A memory apparatus according to claim 1, wherein said active medium is embedded in a supporting matrix.

12. An optical data carrier according to claim 6 wherein said active medium is embedded in a supporting matrix.

13. A memory apparatus according to claim 1, wherein said active medium is chemically bound to a polymeric supporting matrix.

14. An optical data carrier according to claim 6 wherein said active medium is chemically bound to a polymeric supporting matrix.

15. A method of producing a three-dimensional pattern of different response to multiphoton interaction

(a) providing a volume comprising an active medium, having diarylalkene derivatives and being capable of being in either a first or a second isomeric form, said medium being capable of changing from said first to said second isomeric form as a result of multiphoton absorption, and said first and second isomeric forms have mutually different response to multiphoton interaction;

(b) directing to selected portions of the active medium a light beam having only in said portion an intensity that activates multiphoton change of said active medium from the first to the second isomeric form, said selected portions having different X, Y, and Z coordinates;

thereby creating in said volume a three-dimensional pattern of different cross-sections to multiphoton fluorescence.

16. A method of producing a three-dimensional pattern of different response to multiphoton interaction

(a) providing a volume comprising an active medium, having diarylalkene derivatives being capable of being in either a first or a second isomeric form, said medium being capable of changing from said first to said second isomeric form as a result of multiphoton absorption,

(b) transferring by nonlinear process to selected portions of the active medium a light energy having in said portion an energy threshold that activates change of said active medium from the first isomeric form, said selected portions having different X, Y, and Z coordinates.

17. A method of identifying the isomeric form residue of an active medium in a portion of a three-dimensional pattern producible in a method according to claim 15, the method comprising directing to said portion of the pattern a light beam causing predominantly in said portion fluorescence, reading the intensity of the produced fluorescence, wherein said fluorescence being substantially different in intensity in one isomeric form than the other, and thereby identifying the isomeric form residue of the active medium in said portion.

18. A method of identifying the isomeric form residue of an active medium comprising diarylalkenes in a portion of a three-dimensional pattern producible in a method according to claim 15, the method comprising directing to said portion of the pattern a light beam causing predominantly in said portion multiphoton interaction, and reading the intensity of the produced interaction.

19. A method of identifying the isomeric form residue of an active medium in a portion of a three-dimensional pattern producible in a method according to claim 16, the method comprising directing to said portion of the pattern a light beam causing predominantly in said portion fluorescence, reading the intensity of the produced fluorescence, wherein said fluorescence being substantially different in intensity in one isomeric form than the other, and thereby identifying the isomeric form residue of the active medium in said portion.

20. A method of identifying the isomeric form residue of an active medium comprising diarylalkenes in a portion of a three-dimensional pattern producible in a method according to claim 16, the method comprising directing to said portion of the pattern a light beam causing predominantly in said portion multiphoton interaction, and reading the intensity of the produced interaction.

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