Title: MULTILAYER COMBINED LIQUID CRYSTAL OPTICAL MEMORY SYSTEMS WITH MEANS FOR RECORDING AND READING INFORMATION

Abstract: Several embodiments for a new structure of multilayer data carriers of the ROM-, WORM- or RW-type and general modes of writing, reading, deleting and re-writing data to and from them are described. Each data carrying layer is fabricated as a multi-component structure that constitutes a thin electrically controlled liquid crystal cell with at least one alignment layer made of a photo-anisotropic material which functions as a photosensitive registering layer, in which data can be written. The anisotropic absorbing material may be either fluorescent or non-fluorescent. This type of structure ensures electrical control of absorbing and emitting capacity of fluorescent molecules dispersed in the liquid crystal matrix. This, in its turn, allows partial or complete elimination of fluorescent cross talk from the adjacent data carrying layers in the reading mode both in pit-by-pit and page-by-page modes as it increases the number of information layers in the carrier and minimizes parasite aberration distortions in the reading mode.
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MULTILAYER COMBINED LIQUID CRYSTAL OPTICAL MEMORY SYSTEMS
WITH MEANS FOR RECORDING AND READING INFORMATION

BACKGROUND

This invention relates to an optical memory systems for pit-by-pit or page-by-page recording and reading information and more particularly, to ROM, WORM, RW-multilayer optical memory systems or their mixes with fluorescent reading information.

The existing optical memory systems utilize two-dimensional data carriers with one or two information layers. Most of the previous technical solutions in optical data recording propose registration of the changes in reflected laser radiation intensity in local regions (pits) of the information layer. These changes could be a consequence of interference effect on the relief optical discs of CD or DVD read-only memory. (ROM-type), burning of holes in the metal film, dye bleaching, local melting of polycarbonate in widely used CD-write once - read many (WORM) - systems, change of reflection coefficient in phase-change rewritable (RW) - systems, etc. [Bouwhuis G. et al, "Principles of Optical Discs Systems", Philips Research Laboratories, Eindhoven, Adam Hilger Ltd., Bristol and Boston].

To increase recording density these carriers use such methods as transition to shorter wave emission sources in combination with high aperture lenses (high NA objective) [I. Ichimura et al, SPIE, 3864, 2280], a reduced track pitch and increasing the groove depth of the land groove recording type optical disc [S. Morita et al, SPIE, 3109, 167]. New media and methods of information reading are used for high density storage of information [T. Vo-Diny et al, SPIE, 3401, 284], pit depth modulation [S. Spielman et al SPIE, 3109, 98], and optical discs having square information pits arranged in symmetrical patterns [Satoh et al, U.S. Pat. No. 5,572,508].

In U.S. Patent Nos. 4,634,850 and 4,786,792 (Drexler Technology Corp.) use a "quad-density" or "micro-chessboard" format of digital optical data to increase data density and to minimize error at the same time; the data are read by a CCD photo detector array to quadruple the amount of digital data that can be stored optically on motion picture film (or optical memory cards).

Three-dimensional (homogeneous) photosensitive media allow us to achieve such information recording density that exceeds several terabits per cubic centimeter. These media display various photophysical and photochemical non-linear effects at two-photon absorption. The most optimal recording and reading performance in these three dimensional WORM- and RW- information carriers is the process of two-photon absorption by both photosensitive elements and the products of the

In principle, this writing and reading modes would allow us to register information locally in the pits with changed information properties within the information medium (similar to information pits used in traditional reflection CD- or DVD-ROMs).

However, actual implementation of this principle constitutes a big challenge due to the high cost and big size of femtosecond laser sources of emission that are required for this type of recording and also due to extremely low photosensitivity of the media. As a rule, this extremely low photosensitivity of the media is caused by extremely low two-photon absorption cross-section parameters of the photosensitive materials that are currently known to us.

Technologically, the use of multilayer optical information carriers will be more efficient. However, they also place certain restrictions and create additional problems regarding the design and properties of the data carrier medium and data reading modes and devices (and in the writing mode for WORM- and RW - optical memory data), especially deep inside the medium.

In a reflection mode each information layer of the multilayer optical information carrier will be covered with a partly reflective coating. It reduces the intensity of both reading and reflected information beams due to its passing through the media to the given information layer and back to the receiver.

In addition, due to their coherent nature, both beams when they are passing through are subject to diffraction that is hard to estimate and also to interference distortions on the fragments (pits and grooves) of the information layers.

That is why multilayer fluorescent optical information carriers with fluorescent reading are preferable as they are free of partly reflective coatings. In this case diffraction and interference distortions will be much less due to the non-coherent nature of fluorescent radiation, its longer wavelength in comparison to the reading laser wavelength, and the transparency and homogeneity (similar reflective indexes of different layers) of the optical media towards the incident laser and the fluorescent radiation. Thus, multilayer fluorescent carriers have some advantages in comparison to reflective optical memory.
In U.S. Pat. No. 4,202,491 a fluorescent ink layer is used whose data spots emit infrared radiation. Pat. JP No. 63,195,838 proposes a WORM disc with a fluorescent reading mode where a data carrier layer was applied to the matted surface of the substratum. It is absolutely impossible to create multilayer information structures on the basis if the WORM discs due to strong optical dispersion of writing and reading emission. However, it is possible to create multilayer optical discs using fluorescent composites. This technology was described in U.S. Pat Nos. 6,027,855 and 5,945,252, and also in EP 00963571A1.

US Patents Nos. 6,009,065 and 6,071,671 (V. Glushko and B. Levich) describe the devices for bit-by-bit reading of information from multilayer fluorescent optical discs.

Currently, a general requirement for all types of multilayer fluorescent data carriers (optical discs and cards) is that data carriers should have maximal potential volume and density of recorded information, maximal potential reading speed and a high ratio between "signal and noise". We can meet this requirement when we minimize the size of information pits and increase their recording density in each information layer; also when we increase the number of information layers and use shorter wavelength sources of reading emission. To be able to achieve high-speed reading we need to create a maximal potential capacity of the information fluorescent signal.

Actual recording density as well as the rest of the above referenced parameters of optical data writing are determined not only by the wavelength of the recording emission source but also by the properties of the actual registering medium used for recording, input/output modes and optical memory devices.

Some additional requirements should be met if we are talking about fluorescent multilayer memory: recording emission must be absorbed only within the borders of a certain micro-locality of a three-dimensional medium and its writing and/or reading emission should be sufficiently intense to be able to achieve a certain threshold effect. Otherwise, the recording of an information bit deep inside the registering medium will be accompanied by optical property changes along the entire route of the recording beam when it passes through the medium.

In addition, when fluorescent molecules absorb one-photon reading emission we observe specific differences in designing modes of data reading in the form of optical discs and cards.

See Figure 1 and 2 for two possible options of reading within a multilayer informational medium (10 (20), where information carrying layers 11 (21) have been separated by polymer layers 12 (22) that are transparent for reading 17 (23) and fluorescent emissions 24 and 25.

As a rule, disc systems utilize bit-by-bit data reading accomplished by a sharply focused laser beam 23 (Figure 2).
Thanks to space filtering in the process of photoreceiver collection of fluorescent emission (24) coming from information pits (26) we can achieve very little cross talk among the layers. This cross talk occurs due to fluorescent excitation (25) of the adjacent information layers when they are pierced by reading emission (23). Therefore, in the utilization of these data carriers low contrast is quite acceptable (ratio between the difference of background fluorescence intensity I₀ (back) and their sum total \( K = \frac{(I₀ (pit) - I₀ (back))}{(I₀ (pit) + I₀ (back))} \) \( K = 1/2 - 2/3 \) of the registered signal coming from each separate information layer.

As this takes place, separate information layers (21) may be entirely solid. Fluorescent material may fill out both the micropits (information pits) (26) and the space in between (27).

This phenomenon allows us to use the well-known hot molding technologies (injection-compression molding technologies) or the 2P process on the basis of photopolymerizable composition from relief master discs (original discs) with subsequent coating with information carrying layers (21) that is done with the help of either spin coating, or roller or dip coating.

Multilayer fluorescent data carriers, such as optical cards, allow us to use multichannel (page-by-page) reading of entire pages of information (14), which are comprised of several thousands of pits (16); this is what a CCD camera does. As this takes place, three-dimensional image filtering of a page (14) may be considerably hindered by the cross talk between the layers; this cross talk occurs due to fluorescence (25) that is emitted by the adjacent layers, and as a result, we observe a less contrast image received by the photoreceiver, as contrast is really plummeting. That is why it is critical that we should achieve high contrast (\( K \sim 1.0 \)) in each layer while using an optical card. In order to achieve a high level of contrast we should group information layers (11) as an island-like structure, while only information pits (16) must be filled with fluorescent material. To fabricate this structure consisting of data carrying layers we really need to use a fairly sophisticated technology.

Moreover, as fluorescent information pits within the layer occupy about fifty per cent of the entire layer area and even though the percentage of filling out is as large as the one that has been referenced above the intensity of the information signal emitted by this layer and coming to the photoreceiving device is approximately \( 1/N \) part of the intensity of the entire fluorescent flow that reaches the receiver from a multilayer carrier in the reading mode, with \( N \) denoting a number of information layers in it.

This invention offers several options for a new structure of the ROM-, WORM- or RW type of a fluorescent multilayer data carrier and types and modes of writing and reading data to/ from it. These options allow us to electrically control the absorption and emissive capacity of fluorescent molecules
that are diluted in a liquid crystal matrix. In its turn, this allows us to eliminate fully or partially fluorescent cross talk between the adjacent data carrying layers while reading both in the "pit-by-pit" and "page-by-page" modes. In doing so, we also can control the fluorescent intensity of the information signal and shorten the distance between the layers, which in its turn will allow us to increase the number of information layers in the carrier and lower aberrations and distortions in the process of reading. In addition, the proposed solution will enlarge the area of application of various non-linear and linear photochemical and photophysical mechanisms of single writing or rewriting. It will also allow us to employ one and the same source of emission for recording, reading and deleting data in the data carrier.

In addition to that, our invention also contains other designs for the multilayer information carrier that uses photochemically stable, anisotropy absorbent and non-fluorescent substances as host fluorescent substances, while a liquid crystal matrix may be entirely devoid of host molecules.

The specifics and advantages of our invention may seem even more obvious if the readers read the following pages describing in more detail the principles of writing, reading and rewriting data in the information carrier that we have developed. We also supply numerous drawings and illustrations of our invention.

20 BRIEF DESCRIPTION OF DRAWINGS

Fig. 1. Schematic idea of page-by-page data reading from a multilayer fluorescent information carrier with a fluorescent background created by information layers that are not supposed to be read.

Fig. 2. Schematic idea of bit-by-bit data reading from a multilayer fluorescent information carrier with a fluorescent background created by information layers that are not supposed to be read.

Fig. 3. Schematic idea of the cross-section of a generalized option for a proposed structure consisting of the combined multilayer data carrier of the "liquid crystal - fluorescent dye" type.

Fig. 4. Schematic idea of a data carrying layer with transparent electrodes in the form of two mutually orthogonal strips.

Fig. 5. Alignment and switching configuration of the fluorescent - liquid crystal data layer.

Fig. 6. Top view and cross-section of one data carrying layer with and without any voltage in the electrodes.
Fig. 7 a, b. Various options of forming registering layers with patterned aligned surfaces and modes of reading fluorescent signals coming from these surfaces.

Fig 8 a, b, c. Various options for the structure of a combined data carrying layer of the ROM-, WORM- or RW- type.

Fig. 9 a, b. is a schematic plane view of the track shown in optical card and optical disc before (a) and after (b) writing by beam incidence, respectively.

Fig. 10. Typical view of kinetic curves of guidance, deletion and optical anisotropy darkness relaxation in photo-anisotropic materials containing photochemically stable and anisotropy absorbent substances. The up (↑) and down (↓) arrows indicate the moments of turning on and off photoactive emission. Symbols A → B and B ← A indicate those moments when polarized photoactive emission is switched over to the orthogonal mode. Symbols "0", "1" and "-1" signify respectively the starting position and two photoinduced and stable conditions in terms of thermal dynamics.

Fig. 11. Schematic idea of one of the options for a bit-by-bit data writing device when data are recorded on a multilayer fluorescent liquid crystal optical data carrier that ensures bit-by-bit control and adjustment of the quality of data writing in real time.

Fig. 12. One of the designed options for page-by-page control of the quality of the written registering layer of the multilayer combined fluorescent liquid crystal optical carrier.

Fig. 13 Dyes structural formulae.

It should be pointed out that these figures do not illustrate actual size and proportion of their components, as they are designed to facilitate understanding of the structure and the principles of operation of a fluorescent multilayer optical data carrier.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

See below the description of our invention with references to the drawings that support it.

Fig. 3 depicts a schematic idea of the cross-section of a generalized option for a proposed structure consisting of the combined multilayer (to facilitate understanding of its operation principle we have chosen a two-layer) optical data carrier (300) fabricated on the basis of an electrically operated guest-host liquid crystal system.

As its main components the data carrier (300) is equipped with a "pad" (substrate) (301) and includes numerous data carrying layers (data layers) (302), which also constitute a multilayered structure rather
than a one layer structure unlike well known fluorescent data carriers that are described in [U.S. Pat. Nos. 6,009,065; 6,071,671; WO 99/24527 et al]. In general, it has been designed as thin liquid crystal cells (LCC) that can be operated electrically and consist of two similar optically transparent electrodes (3030 coated with alignment layers (304 and 305) that are separated by spacers (306). The space between alignment layers that is divided by spacers (306) is filled with guest-host liquid crystal (LC) composition (307), containing photochemically stable, anisotropy absorbent fluorescent materials (308) that are used as host substances (308).

We have selected those substances that can dissolve well in liquid crystal compositions and are highly fluorescent as they emit a high number of photons (quanta), as we needed photochemically stable substances that become fluorescent in the set specter and are capable of anisotropy absorption. In these substances the molecules are aligned in tough, rod-like or disc-like clusters, and their long-wave absorption oscillator is directed along their long axis (like in stilbenes, for example) or across the axis (like in tetracene, pentacene and other polyacenes).

In our invention these fluorescent substances have been selected from the photochemically stable compositions that comprise the group of aromatic carbohydrates and their derivatives, such as multicore condensed aromatic carbohydrates; also those carbohydrates that include arilethylene and arilacetylene groups and their derivatives (1,2- diareiletylene, diarilpolynes, stilbene functional replacements and 1,4-distyryllbenzol replacements, etc) and polyphenyl carbohydrates; compositions containing five- (furans, thiophens, pyrroles and their derivatives, etc.); heterocyclic compositions; compositions containing the carbonyl group (coumarin and carbostenated substances, anthron and aromatic acids derivatives; oxazol-5 replacements, indigoids and thiindigoids, quinones, etc); naphthalic acid compounds; and also complex compounds of metals with organic ligands and organic dyers of the xanthene group, acridine group, oxazine group, azine group, periline group, teriline group, vialonthrone group, cyanine group, phtalocyanine group, porphyrine group, etc.

Liquid crystals and dye have been mixed in a molar ratio between 1: 0.01 and 1: 0.8. For liquid crystals one can use thermotropic or lythropic smectic or cholesteric liquid crystals or their mixtures, however, nematic liquid crystals or their mixtures with other crystals are more preferable.

Photochemically stable, anisotropy absorbent materials may have covalent connections with the molecules of the substance with liquid crystal properties. It is liquid crystal substances that may play the role of a fluorescent agent as they are capable of fluorescing when they are affected by emission and absorb it.
Data layers (302) have been separated by "intermediate layers" (309) that are optically of good quality and are transparent for writing and reading emission, which is also capable of carrying data (fluorescent) and deleting. The intermediate layers are from several to several hundreds microns thick. The protection layer (310) protects the optical data-carrying medium from mechanical damage and the harmful effect of aggressive media. To eliminate the parasitic effect of light reflection, scattering and diffraction caused by the out-of-focus layers it is critical that we should select those refraction parameters for all data, intermediary and protection layers that are very close to each other for the given wavelengths. The same parameters should be also selected for the guest-host LC composition (307), which may be in a homeotropic (or planar state depending on its nature and reading and/or writing modes). If required, the data layer (302) for the set wavelength may be fabricated as a multilayer with an antireflection and interference coating. To fabricate this type of layer we should add to its structure some additional layers (not indicated in Fig. 3).

Data layers and intermediate layers are glued together into one multilayer carrier (300) with the help of glues that solidify when exposed to light or heat (311).

Controller 312 ensures individual electric control. It uses electric power supply coming from Source 313 and helps align LC molecules in Composition 307 and, consequently, host fluorescent molecules (308) which are part of this composition. Controller 312 and power supply source (313) are located outside the multilayer carrier (300), as they are installed in the independently operating data writing and/or reading device (not indicated in Fig. 3).

For optically transparent electrodes (303) we have used transparent electrode layers that are commonly used for PC liquid crystals (LC) screens. They are made of metal oxides, such as indium tin oxide (ITO), tin oxide, etc. They are approximately from 0.001 to 1 mm thick. They may be manufactured as a homogeneous film (303) or as two mutually orthogonal strips (Fig. 4) 41, 42 to save electric power in the general modes of writing, reading or deleting data to (or from) the multilayer carrier. In the latter case each of the liquid crystal cells functions as shutters array that controls the coefficient of the host fluorescence excitation (308) passing through the spectral area in writing, reading or deleting data in the given area (page) 43 of one of data layers (302) of the multilayer carrier (300). It also controls fluorescence intensity. Both sides of intermediary glass or polymer layers (309) are coated with electrodes (303) (for glass or polymer one can use Mylar (Dupont), polycarbonate, epoxy resins, photosensitive resins, photopolymerizable composites, etc). It is preferable that intermediate layers should be isotropic as far as their optical properties go.

To make a homogeneous surface of the alignment layer (304) we may use those alignment layers that are traditionally employed in liquid crystals (LC) screens technology. This technology has already
been described in [P. Chatelain, Bull. Soc. Franc. Miner. 66, 105 (1943)]. The method uses polymer films of the polyimide type that are less than one micron thick. The film is mechanically rubbed in one direction and it coats one of the transparent electrodes (303) (Fig. 3) or one of electrodes 41 or 42 (fig. 4).

However, this technology is less applicable or not applicable at all when the intermediate layers are too thin (about 10 mm or less) or when the layer uses a microrelief surface (309). In this case we may resort to other known technologies that use non-contact methods of planar alignment of liquid crystals layers, for instance the method of slanted spraying of certain transparent materials [J. L. Janning, Appl. Phys. Lett. 21, 173 (1972)] or use of the Langmuir-Blodgett multimolecule films [E. Guyon, Vac. Sci. Technol. 10, 681 (1973)].

For our invention we have used the technology that ensures liquid crystals alignment with the help of the so-called photoanisotropic materials, that is naturally isotropy photosensitive materials, which display optical anisotropy when they absorb polarized and even non-polarized but guided optical emission. This technology was discovered in 1990 by one of the authors of this invention [V. Kozenkov et al. 11 USSR Optic Liquid Crystal Conference, Krasnoyarsk, 1990, p. 130 (in Russian)].

Optical anisotropy is caused by the anisotropy of the aligned molecular distribution both within the depth of the material and on its surface. These may be the remaining initial molecules with anisotropy properties or new anisotropy products formed as a result of photochemical reactions. As this takes place, and when activating emission safely reaches the photoanisotropic material the prevalent alignment of the permanent dipoles in the remaining initial molecules will follow the material plane and will be aligned orthogonally to the electric field vector of the activating emission.

As a result of this alignment we achieve a combination of anisotropic molecules that are sitting on the surface of anisotropic materials and the anisotropic products formed as a result of photochemical reactions. This combination is capable of aligning the molecules of liquid crystals along the plane and in a certain direction following the direction of the prevalent alignment of the photoanisotropic material surface molecules.

In our invention the layers made of these materials may be manufactured using the centrifuge technology, solution dip or following the Langmuir-Blodgett method, or by vacuum thermal spraying. The non-contact and non-mechanical optical method of adding alignment properties allows us to fabricate super thin intermediary layers (309) or micro-relief surface layers, when only one of the layer surfaces is coated with micro-relief.
When thin LC cells are used for data layers (302) one may do without the alignment layer (304).
In our invention the alignment layers (305) located on the inverse transparent electrode 303 (Fig. 3) or on Electrode 42 (or 41) (Fig. 4) in addition to their alignment role also play the role of registering layer. The layers can be manufactured by mechanical rubbing of polymer layers, their slanted spraying or made of the Langmuir-Blodgett films (for data carriers of the ROM type). We can also use the above referenced photo alignment method that works well with photoanisotropic materials (for data carriers of the ROM-, WORM- or RW type).

In the latter case after writing has been completed the layers will contain numerous micro-areas that will carry data (information marks or pits) that are similar to reflecting pits in traditional CD or CD-ROM systems) 314. They will be located in the background areas (315) and will have different molecule clusters, and, consequently, different alignment capacity as compared to the electrically controlled LC composite guest-host layer 307, both in the outward surfaces (316 and 317) and within the LC layer (307) respectively.

Simultaneously with the electrically controlled orderly alignment of the LC molecules the clusters of the host fluorescent anisotropic molecules (308) that have been diluted in the LC are also becoming more ordered and aligned, and they start absorbing reading emission. As this takes place, depending on the presence or absence of voltage on electrodes 303 or 41 and 42 the absorption coefficient and fluorescence intensity of the data carrying layers will change too.

This technological solution in the application of photoisotropic materials as photo-alignment layers has a certain number of advantages as compared with the contact and non-contact non-optical methods of LC molecules alignment that were used before. Thus, we may list the following advantages:
- simplicity of forming photopatterning alignment surfaces with the set spatial configuration of the surface alignment capacity;
- better alignment of LC molecules on the surface in terms of optical quality, and
- possibility of controlling their adhesion W3 with the molecules of the alignment layer surface.

The latter is of critical importance, as in high density surface data writing in the data layer (302) the LC layer thickness must be correlated with the size of the information pit, recorded in the registering layer (305), in other words, if the pit is approximately 0.4 mmc the LC layer should be about 0.1 - 0.4 mmc thick.

Incidentally, it is common knowledge that in highly adhesive (W3) alignment surfaces and in actual electric fields that control the process it is impossible to realign molecules electrically, for instance, in
nematic LC in the areas that are approximately 0.01 mmc thick. In other words, it is impossible to do it in those layers that are comprised of several molecular layers having direct contact with the interphase. Obviously, if we control the energy of photo exposure of a photoanisotropic material we will be able to not only form the axis of the LC planar alignment but also control adhesion energy value ($W_A$), that is adhesion between LC molecules and the surface molecules of the photoaligner, and, consequently, we will be able to affect their electro-optical behavior.

Thus, in our invention the proposed electrically controlled multicomponent electric structure of the data layer (302), the layers (304) (if they are available) play a traditional role of alignment layers, while the alignment layers (305) also operate directly as a registering layer of the ROM-, WORM- or RW type. As this takes place, a hidden pattern of information pits is being formed taking shape in the process of changing alignment properties and the changes are modulated along the surface in relation to the LC molecules. When necessary, this pattern may be read automatically (visualized) with a high degree of fluorescence intensity, which is done by a guest-host liquid crystal cell in the data carrying layer 302. This layer also includes the alignment and registering layer (305) that uses anisotropic absorbent fluorescent molecules as a host (308).

The proposed combined fluorescent multilayer optical data carriers may be fabricated as CD- or DVD-read only memory (ROM), write once read many (WORM), rewritable (RW) or their mixed types in a variety of optical discs, cards or tapes. The geometry of the two-dimensional distribution of information pits along the space of such carriers may be depicted as a straight line, or it may be a spiral-like or a circle-like track, where the data flow is written with the help of EFM (eight-to-fourteen modulation) 14 digit channel modulation code. Data may also be written in the form of four adjacent bytes registerd with the help of the ETT (eight-to-ten) method of two-dimensional data encoding on the surface of the alignment and registering layers (305).

It is possible to control fluorescence intensity by way of changing the alignment of axes of dichroism molecules (308) that emit light directed towards reading emission that excites fluorescence. As a result of dichroism property of the absorbing fluorescent material (308) the light that is emitted by it is of maximal intensity. However, to achieve the maximum intensity the molecules should be aligned in such a manner when their absorption of reading emission is maximal. Changing the direction of the liquid crystal matrix (307) with the help of the electric field created by Controller 312 we can control the intensity of absorption of reading emission by fluorescent molecules (308) and, consequently, the intensity of fluorescent data carrying light emitted by them. If necessary, we can smoothly change the electric field parameters and the intensity of fluorescent light will also change smoothly, without changing the intensity of reading emission.
For instance, the proposed optical memory system may be structured on the basis of electrostatic deformation of homeotropic textures of nematic LC (501) with negative dielectric anisotropy or homogeneous (planar) textures of nematic LC (502) that are aligned in one direction and have positive dielectric anisotropy properties. These deformations are accompanied with correlated alignment changes in the molecules of dichroism fluorescent substances (503) that are diluted in the nematic matrix (504) (Fig. 5a).

Nematic liquid crystals, for instance, those that have positive dielectric anisotropy, perform the function of a matrix that aligns elongated molecules of substances with dichroism properties (503) and position them parallel to each other and also parallel to the molecules (502) of the LC layer. Changes in the alignment of the liquid crystal matrix in the electric field will entalp changes in the alignment of the dichroism material (503), and, consequently, changes in absorbing (theoretically up to zero) and fluorescent capacities (also up to zero) of the thin guest-host LC layer (504) in relation to reading (or writing) and deleting emission (505).

For instance, if we want the dichroism molecules (503) to be aligned parallel to the electrode surface (303) when no voltage is supplied (V=0), we need to form an aligned planar structure in the nematic sample with positive dielectric anisotropy (502). In addition, we need to select molecules with dichroism properties (503) in such a manner that at the set wavelength they will absorb reading emission to a maximum degree (Fig. 5b, Curve 1) and, consequently, ensure maximal fluorescence in the reading mode (Fig. 5b, Curve 1'). When affected by the electric field $V = V_1$ the positive anisotropy nematic LC (502) that we have selected as a matrix will change its texture and become homeotropic, while the molecules of the dichroism substance (503) will align perpendicular to the oscillation direction of the electric vector of the light wave which may be polarized or non-polarized. The molecules will be practically transparent, so absorption at the wavelength of reading emission, and, consequently, fluorescence will be non-existent (Fig. 5b, Curve 2 and 2' respectively).

As this takes place, the fact that fluorescent background (506) is no longer present in all the out-of-focus layers, except in the layer that is being read, allows us to eliminate fluorescent cross talk produced by them and increase the ratio between "signal and noise" in the reading mode. We are able to minimize the absorption capacity of Layer 504 practically to zero, and this will allow us to use photoanisotropic and fluorescent materials with fully or partially overlapping absorption ranges.

To save electric power used by the reading device it is preferable that we should use nematic crystals with negative dielectric anisotropy. When no voltage is supplied to the electrodes (303) all the data carrying layers (302) will not absorb reading emission and, consequently, will emit no fluorescence. Control power supply to the electrodes (303) (or to specific strips of electrodes 41 and 42) is required only for reading from the set data layer (302) or the set data page (44) of this layer.
Another advantage of the proposed multicomponent structure of the fluorescent data carrying layer 302 as compared with the existing single layer fluorescent data carrying systems is in that the registering layer (305), which also serves as a photopatterning and alignment layer in relation to the guest-host composition 307, may be as thin as you like, up to a single layer which may be just ten Angstrom thick. At the same time its absorbent capacity will be also very small but the intensity of reading, writing and deleting emission practically will remain the same (will not go down) in the process of its passing through such a multilayer medium.

In addition, in conditions of full or partial overlap of ranges of absorption of the photosensitive alignment and registering layer (305) and anisotropic absorbent fluorescent material (308) it is possible to control the absorption capacity of anisotropic fluorescent molecules with the help of electricity. This will allow us to write, read or delete data in the WORM or RW type carriers with the emission source using one and the same wavelength. Moreover, we will have more opportunities to use various linear and non-linear photochemical and photophysical devices for single writing or rewriting data.

It should be pointed out that decrease in the thickness of the photosensitive registering layer (305) up to the size of a single molecule layer will not affect its photosensitivity in the process of data writing, nor will it affect the parameters of the data (fluorescent) signal in the process of reading, as is often the case with traditional single layer fluorescent registering layers. This is achieved by the fact that the data that is being written will be stored as changes in the alignment properties of the registering layer (305) surface (316), while the data carrying signal in the reading mode will be enhanced by electrically controlled guest-host LC layer (307) with fluorescent molecules (308). Signal enhancement will not depend on the thickness of the registering layer (305) and will be affected only by the thickness of the LC layer (307) and the concentration of the fluorescent substance (308) in it. The proposed reading technology does not envisage any changes in the size of the information pit (314). Moreover, it is preferable that we should make it as thin as possible to eliminate parasite diffraction effect of the writing and (or) reading emissions coming to the data pits from the out-of-focus layers.

For better illustration of the principle of operation of this data carrier see Fig. 6a, b that provides a schematic top view (Fig. 6a) and a cross-section (Fig. 6b) of one such multicomponent data layer (302), a proposed data carrier (300), of the WORM- or RW type when there is no controlling voltage V (V = 0) on the electrodes (303) and when voltage is available (V = V1).
Arrows (601 and 602) in Fig. 6a indicate alignment directions on the surfaces 316 and 317 of the information pit (314) and the background area (315) respectively, and, consequently, the direction of the optically shaped photopatterning registering and aligning layer (305). For instance, they may be positioned at an angle of 90°, while the alignment direction (603) on the surface of the homogeneous layer (304) may be parallel to the alignment direction (601) in the area where Pit 314 is located in Layer 305.

As this takes place, the three dimensional image (pattern) of the guest-host LC layer (307) takes up the shape of an optical patterning, where liquid crystal (604) molecules and fluorescent molecules (605) located in Area 608, which is positioned across from Surface 316 of the information pit (606), are aligned parallel to alignment direction (601) on the drawing plane. Area 607 located in front of the background area 317 looks like a twisted nematic, where liquid crystal molecules (604) and fluorescent molecules (605) located on the layer surface (304) are aligned parallel to the drawing plane. On the opposite surface they are aligned orthogonally to the surface, in other words, in a case of a twisted effect the directions of the LC planar alignment on the opposite electrodes will form right angles.

In the reading phase this multilayer structure of the data carrying layer (302) at zero voltage \( V = 0 \) is subjected to linear polarized emission emitted by the registering layer (305) with the help of a polarizer (609) with polarization (611) that is shown on the drawing plane. In this process reading emission will be absorbed and, consequently, re-emitted (612) \( I_\pi \) (pit) by the molecules (605) of the fluorescent substance. However, this phenomenon will be observed only in the areas of the LC Composition 608 before the surface (316) of the information pits (314), while the areas (607) of the LC Composition that are located across the background surfaces (317) will be transparent when exposed to this emission in conditions of this type of reading emission polarization. Visually, we will observe a fluorescent pattern of the information pits against the non-fluorescent background \( I_\pi \) (back). Fluorescent emission will be also polarized. If we activate an additional polarizer, which is positioned in front of the photo-receiving device, we will be able to avoid some of background overexposure to outside emission (Not shown in Fig. 6).

When the direction of the writing emission polarization plane changes to orthogonal it may cause a negative reading mode, i.e. we will observe a luminous background with non-fluorescent information pits. To eliminate fluorescent cross talk from other layers in the reading mode voltage should be supplied to them as it is shown in Figure 6b. As a result all LC molecules in the matrix (614) and the LC fluorescent molecules (613) in the matrix will align perpendicular to the electrodes, while the out-of-focus layers will become fully transparent for reading emission.
When voltage is unavailable and the LC materials have negative dielectric anisotropy, fluorescent substances will align orthogonally toward the electrodes and will not absorb reading emission, which will be directed orthogonally to the layer. In the reading phase voltage is supplied to the selected data layer and as a result the LC layer (307) with molecules of fluorescent substance (308) will acquire a patterning appearance with planar directed alignment correlated with the data recorded in the registration and alignment layer (305).

By way of example, Figure 7 illustrates several options of forming registration and alignment layers (305) made of photo anisotropic materials, when information is recorded in the form of patterning alignment surfaces and corresponding types of traditionally intense fluorescent reading signals in different states of polarization of reading emission. As this takes place, the fact that an information pit may be available or unavailable in the given micro-area of the carrier is detected quantitatively thanks to the difference in fluorescent intensity between information pit locations and the background. The same is also true of regular fluorescent methods of reading information, for example, those that are described in [U.S. Pat. Nos. 6,009,065 and 6,071,671 (Glushko and Levich.)]

Figure 7 a illustrates the fact that information pits (701) and background areas (702) have surfaces that are positioned orthogonally towards each other, the same is true of their alignment abilities (703 and 704). This arrangement of patterned registration layers (305) ensures maximum contrast, which equals $K = +$ or $-1$ (positive or negative) when reading is done by linear polarized (705 or 706) emission. However, non-polarized emission (707) cannot be used for this purpose, as in this case contrast will go down to zero if we use a traditional reading method based on intensity.

This disadvantage can be corrected by the data reading method, which we propose in our invention. This method is capable of detecting a signal which is sent by the presence or absence of anisotropy properties rather than by the difference in the intensity of the fluorescent signal (for instance, various degrees of polarization) in the fluorescent signal when polarized or non-polarized reading emission is being absorbed. Our technology is also capable of detecting differences in the direction of polarization optical axis.

Indeed, fluorescence of individual anisotropic absorbing molecules is also anisotropic. So, in case of the configuration that is aligned in space and shown in Figure 7a fluorescent data carrying emission will be polarized not only when reading is being done by linear polarized (705 or 706) emission, but also by non-polarized (707) emission. And, in case of non-polarized emission, polarization vectors of fluorescent luminescence for the area of information pit location (701) and the background area (702) will be positioned orthogonally toward each other and can be easily identified with a polarizer placed in front of the photo-receiving cells of the reading device.
Figure 7b shows another possible configuration, when background areas (708) lack alignment properties (709), and the information pits surface (710) ensures directed planar alignment (711). In this case regular reading technology based on intensity also allows us to employ polarized (714) and non-polarized emission (712), where contrast can be determined after the module $K = 1/3$, while polarized emission (713) ensures contrast that equals $K = -1$ when the intensity of fluorescent signal $I_b$ (back) becomes twice as little as its maximum value. In conditions of polarized reading emission (713 or 714) mode the polarization of a luminescent signal, for example, can be detected with the help of an optical system that will include a switching modulator, which rotates reading emission polarization plane, and a photo-receiving device for subsequent photo-electrical detection of an electric signal variable component sent by fluorescent luminance at a double rotation frequency of reading emission polarization vector. As this takes place, the intensity of fluorescence emitted by the background area (709), which includes randomly aligned fluorescent molecules, will not change and the constant component of the electric signal sent by this emission will be cut off.

When non-polarized reading emission (712) is applied, polarized fluorescence will be emitted only by information pits (711) and its presence can also be detected by adding another polarizer placed in front of the photo-receiving device. Single-photon reading – both by its intensity and its polarization – will allow us to perform both bit-by-bit and page-by-page reading.

This invention offers a multi-component structure of fluorescent data carrying layers, which use photo-anisotropic materials to form alignment and registration layers and liquid crystal compositions of the guest-host type. Photochemically stable fluorescent substances capable of anisotropic absorption have been used for "guest", which allows us to create optical carriers of the ROM-, WORM- or RW-type. In addition, multi-component data layers of the ROM type can also be manufactured making use of alignment layers that are traditionally used in liquid crystal screens.

Figure 8a shows one of the options for the proposed data layer of the ROM type (810), which uses a spacer (811) located between equally thick dividing layers (812) that use transparent electrodes (813) and aligning layers (814) that ensure alignment in the same direction.

In this particular case Spacer 811 not only ensures the necessary thickness of the LC guest-host layer with fluorescent molecules (815) in information pits (816) but also plays a role of a data layer of the ROM type. It has a three-dimensional patterned appearance and can be fabricated from photosensitive acrylic resin or positive or negative photoresistor. The data, which is recorded in it, can be formed by traditional methods of contact or projection lithography or electronography, or by scanning modulated laser emission along a photosensitive surface with subsequent development. As aligners (813) one can use either photoaligners made of photo-anisotropic materials or traditional LC
aligners. In our invention one or even both aligners (813) may be missing in the diagram shown in Figure 8a.

Figure 8b presents another option for a multi-component structure of a fluorescent data layer (820) of the ROM type. Here the dividing layers (821) with data carrying micro-relief surface (822) and flat surface (823) are fabricated like reflecting CD- or DVD- optical disks using the injection-compression molding technologies or the 2P-process on the basis of photo-polymerizable composition. Transparent electrodes (824) have been sprayed on both sides of the dividing layer (821) and coated with alignment coats 825 and 826. To eliminate possible damage of the data layer (826) we have used an optical method and photo-anisotropic materials to develop its alignment properties. Information pits (827) were filled with guest-host LC composition 828 with fluorescent substance. Like in the above referenced case, here at least one of the alignment layers (825 or 826) may be missing.

Figure 8c shows one of the proposed structures of the data layer (830) of the WORM- or RW-type. Here the dividing layers (831) with flat surface (823) and surface (833) with straight, concentric or spiral-like tracks or channels (834) are fabricated using the injection-compression molding technologies or the 2P-process on the basis of photo-polymerizable compression. The size and shape of the tracks are selected based upon the alignment properties of the guest-host LC 835 with fluorescent molecules 836 and the desirable tracking mode. Transparent electrodes 837 are sprayed on both sides of the dividing layer (833). If the LC layer 835 is too thin (less than one micron), the alignment layer (838) may be missing, and the alignment layer (840) will be made of photo-anisotropic materials.

When one and the same emission source is used for writing or deleting data, these processes occur in the mode of homeotropic alignment of the guest-host LC composition (839) in all data layers that come before the set layer, and also in the set layer; and in the reading mode these processes also are repeated in all the layers with the exception of the layer that is being read, where the LC composition (839) is aligned along the plane.

Figure 9a, b shows the alignment and registration layer (305) (top view) of the proposed multicomponent structure of the data layer (302) of the WORM or RW type, whose generalized view is depicted in Figure 3, before (Figure 9a) and after (Figure 9a) data is written on it. Tracks 911 (922) for data carriers that have been fabricated as an optical card 910 (or optical disc 920) are located right in the alignment registration photosensitive layer 912 (922) which is made of photo-anisotropic material. This layer 912 (922) also serves as a photopatterned and photoalignment layer for the guest-host LC composition layer made of photo-chemically stable anisotropic absorbing fluorescent molecules in the first multi-component data layer 302. For instance, this layer has background areas
913 (923) with randomly aligned molecule clusters 914 (924). It also has straight (for optical cards 910) or spiral-like (for optical discs 920) tracks 911 (921), where molecular clusters have prevalent alignment 915 (925) in most cases. In this case the direction of the prevalent alignment (See Figure 9 where they are indicated with arrows) of these molecular clusters may be positioned at a certain \( \Psi_1 \) angle in relation to the track, as in the case of straight tracks (911) of the optical card (910), or they may be located along (across) the track as in the case of concentric tracks (921) of the optical disc (920).

This surface structure of each alignment registration photosensitive layer-i 912 (922) is directionally modulated along the orderly molecular alignment. This alignment can be achieved through exposing this i-layer (before fabricating a multilayer data carrier 300) to linear polarized emission (not shown in Figure 9) focused and scanned along the surface which is absorbed by the layer photo-anisotropic material, as the initial molecular structure of this layer is not yet aligned 914 (924).

It is also possible to employ projection or contact photo printing by polarized emission, as this photolithography technology has become quite common today. This emission goes through metal plated positive photo-templates with transparent tracks. To fabricate a structure with non-aligned tracks 911 (921) one needs to use negative photo templates against the aligned background 913 (923).

Later we can fabricate multi-layer combined fluorescent liquid crystal optical carriers. They are made using those alignment registration layers with given angle \( \Psi_1 \) that we have prepared earlier. One side of the intermediate layer (309) is coated with them and also with an electrode 303.

As we have already mentioned, when the data is being recorded on one of registration layers of the multilayer carrier, we may achieve the desired absorbing capacity of all multi-component data layers (302) by applying electric voltage prior to that, this power is supplied to them from an outside controller (312).

Further on, in a bit-by-bit writing mode the writing beam (not shown in Figure 9) is focused on spot 916 or 917 (926 or 927) in the track location area 911 (921) and is partially absorbed by the registering medium 912 (922) made of photoanisotropic material. As a result of photo-physics, photochemical or photothermal processes the initial molecular clusters within the substance and – what is the most important – on the surface of the exposed area 916 or 917 (926 or 927) are modified, and those changes also entail the changes of its aligning ability in relation to the guest-host LC layer 307. These changes depend on the type of the photoanisotropic material and the parameters of the writing pulse (distribution of intensity and energy of pulse in time and space, pulse duration, polarization state and direction of writing emission polarization vector in relation to the alignment of
molecular clusters 915 in spot 916 or 917 (926 or 927). These changes can manifest themselves as changes (or formations in the negative case) in the direction of space alignment of surface molecules 918 (928). For instance, their alignment direction may change to orthogonal in the microarea 916 (926), or they may become completely misaligned 919 (929) in the micro-area 917 (927) in a positive case, shown in Figure 9. The alignment of LC layer 307 that is in direct contact with the modified surfaces 918, 919, 928, and 929, changes accordingly.

The first option of recording uses photoanisotropic materials with photochemical or photo-physics recording mechanisms, where writing is done by polarized emission with polarization vector pointing, for example, orthogonally in relation to the initial molecular alignment 916 (926) in tracks 911 (921).

The second option employs a photothermal recording mechanism, where writing is done as a result of the micro-area melting 917 (927) with the subsequent loss of molecular alignment 919 (929) when the material cools down. Data pits written by this method can be read in modes shown in Figure 6 and Figure 7 by both an emitting source with a different wavelength absorbed by fluorescent molecules of the LC composition and also by the same emitting source that was used for writing. However, in the latter case we must employ lower emission intensity.

It should be pointed out that it is not altogether true to present all oscillators that anisotropically absorb fluorescent molecules as linear oscillators. So, such molecules, even when the are aligned in perfect homeotropic clusters, will absorb some of the reading emission. In addition, as it was mentioned earlier, near-surface areas, for example, of nematic LC and, consequently, the fluorescent molecules dissolved in them that come into direct contact with the interphase of the alignment registering layer 912 (922) cannot completely realign themselves when affected by the electric field.

All this can result in incomplete loss of illumination of the fluorescent background consisting of the out-of-focus layers. In our invention we tried to eliminate this phenomenon with greater efficiency, so we employed additional codes that is angle $\Psi$ individual values. The direction of primary alignment of molecular clusters 915 (925) toward tracks 911 (921) of each of registering layers 912 (922) of the multilayer data carrier 300 is has an additional characteristic as it is encoded with angle $\Psi$ individual values. This is used in the reading phase for additional polarized isolation (decoding) of anisotropic (partially polarized) fluorescent emission of the layer that is being read. It helps isolate this layer from anisotropic partially polarized fluorescent emission coming from all other out-of-focus layers.

All photoanisotropic materials are characterized by their reversibility, regardless of photochemical or photo-physics mechanism that causes their optical anisotropy and, consequently, their ability to
realign LC. In this case optical anisotropy as well as their aligning capacity may be deleted. In other words, certain locality data recorded in the registering photo-anisotropic layer can be optically or photo-thermally deleted. In this registering layer we are able to delete written data completely by using a purely thermal method, that is heating the entire layer.

Data may be restored (or rewritten), employing the same modified alignment of the optical axis of guided anisotropy that has been polarized by initial optical emission with the same or different polarization vector. However, the number of these reversibility cycles depends on a specific mechanism of creating optical anisotropy in these materials.

Our invention proposes using photoanisotropy materials based on monomolecular irreversible photochemical reactions or bimolecular photochemical reactions in the data carriers of the WORM type. In the latter case we may use those materials that are made on the basis of low or high photosensitivity substances, for instance, the group of diacetylene derivatives, such as Langmuir-Blodgett multimolecule films or sprayed films of nonacozadine of 10, 12 - carboxylic acid [Kozenkov V. et al, SURFACE. Physics, Chemistry and Mechanics, 2, 129, 1989, or polyvinilcynnamate [Kozenkov V. et al, Presentations, the USSR Academy of Science, 1977, 237. 3, p. 633] However, their reversibility is small and is restricted by the number of photosensitive molecules that are spent in the photochemical process in each cycle. However, these materials can be used for the purposes of our invention as the WORM type registering medium on condition that we eliminate their molecular rotation.

In addition, we can also make use of small reversibility of their photo-induced anisotropy to introduce corrections into the written data right in the process or recording or after writing has been completed.

Most photochrome materials also display the effect of photo-induced optical anisotropy. However, they are not very useful for the purposes of our invention, as they also display reverse emissivity relaxation and have a fairly high quantum release resulting in the irreversible destruction of photochrome molecules both in the initial and/or photo-induced states.

For the purposes of our invention we can make the best use of those photo-anisotropic materials that are made of photochemically stable, anisotropically absorbent and non-fluorescent substances. Unlike those materials that display the effect of photo-induced optical anisotropy as a result of various reversible and irreversible photochemical reactions (the Weigert effect), in these materials optical anisotropy is created as a result of a photo-physics process of molecular alignment when the substance molecules absorb polarized and even non-polarized but guided emission. Incidentally, this process does not entail any chemical or conformation changes in the molecular clusters.
As this takes place, a greater part of anisotropic, photochemically stable and non-fluorescent molecules are aligned either along the plane, which is positioned orthogonally to the light wave electric field vector, or in the direction of its propagation in case of non-polarized emission. These materials are photochemically stable, and thanks to them we are not only capable of making corrections in the recorded data but also ensuring an indefinite number of "writing-deleting" cycles; in other words, one can write and rewrite data on them indefinitely. This data may be stored for many years to come. In addition, these materials allow us to read data without destroying it.

Moreover, in the proposed invention all operations that involve writing, reading, deleting and rewriting data in such media can be performed by one and the same emission source. We do not even need to reset its parameters (time, power and polarization light pulses). These materials can be used as ROM-, WORM- and RW type data carriers. These combined multilayer data carriers are particularly promising, as their composition can also include registering layers of the ROM-, WORM- and RW type. These layers may be made of materials with similar or different composition. This fact will considerably simplify the technology of manufacturing these combined multilayer data carriers and enlarge the range of their functions.

Photochemically stable, anisotropically absorbent non-fluorescent substances that are used in these photo-anisotropic materials may be introduced into polymer matrixes at a molecular level or they may be used as homogeneous single substance films with a small number of special additives that will improve their film-forming properties.

See Fig. 10 for these possibilities as it shows typical kinetic graphs of guidance and optical anisotropy emissivity relaxation (two-beam refraction) in a single substance film affected by polarized emission in the various phases of its guidance or deleting.

As you can see from Fig. 10, the material displays isotropic properties in its initial thermodynamically stable state. We may regard this state as logical zero "0". When data is written in the process of radiation the material acquires optical anisotropic properties and anisotropy is reaching its photosteady parameter in an asymptotic manner (Graph 1). When exposure is very short (or power is insignificant) we may observe the process of emissivity relaxation (Graph 2), which results in complete or partial lowering of guided anisotropy up to a certain stable value which will grow with the growth of the exposed layer energy. This lowering occurs as a result of the Brownian molecular rotation diffusion that can lead to random misalignment of photochemically stable molecules. However, when exposure energy becomes higher the speed of emissivity relaxation is slowed down and even becomes non-existent (Graph 3).
Moreover, with sufficiently high exposure (approximately at 0.1 - 1 nJ/μ²) shutdown of activating emission will result in the further orderly self-alignment of molecules in the layer (Graph 4) and they will reach a new thermodynamically stable state. The speed of this "emissivity relaxation that is directed upwards" is growing with the growing heat in the layer. This highly aligned state may be regarded as logical "1". This state continues to be stable until the temperature reaches the melting temperature of the photo-anisotropic material.

Maximum values of this photo-induced optical anisotropy in these media approach corresponding values in the liquid crystals. Thus, the alignment order parameter S may be presented as follows:

\[ S = \frac{(D_{11} - D_{1})}{(D_{11} + 2D_{1})} \]  
(1)

and

the value of two-beam refraction \( \Delta n \):

\[ \Delta n = n_1 - n_{11} \]  
(2)

These values can reach 0.8 and 0.3 respectively.

Here:

\( n_{11} \) and \( D_{11} \) are the values of refraction indicator and optical density of material for the polarization component vector of the measured emission created by activating emission polarization that may be parallel or perpendicular to the polarization vector of activating emission, respectively.

We have established that the photo-induced state (including orderly alignment of surface molecules) in these materials may be preserved at least for more than 10 years.

Fluorescent reading of data that has been written in this manner may be performed in the modes that are illustrated in Fig. 6 and 7. However, short-term or low intensity exposure of this orderly aligned layer to a similar but non-polarized or circular polarized emission source will result in its partial misalignment (Graph 5), leading to partial deterioration of its alignment properties as regards liquid crystals. We may achieve the same result when we change the direction of the reading emission polarization vector and make it orthogonal. However, when the emission source is shut down, the photo-induced and thermodynamically stable state can be restored (Graph 4'); the same is true of the liquid crystal alignment properties. This characteristic of photo-anisotropic materials made from photochemically stable anisotropy absorbing non-fluorescent substances allows us to read data practically without damaging it in any way, when data is recorded in the proposed multicomponent fluorescent data systems and these materials are used in the alignment and registering layer. In addition, interaction between the symbol and speed of emissivity relaxation (Graph 2, 4 and 4') helps
eliminate optical anisotropy "background" targeting of the out-of-focus layers in the writing mode, as we may induce "self-deleting" if absorbed energy is too small (See Graph 2, Fig. 10).

Deleting recorded data may be done in the same mode as reading; however, it requires more emission energy. In this process we may observe either complete thermal (photo-thermal) molecular misalignment (and loss of their capacity to align liquid crystals) in the microarea that is being deleted (Graph 6). This is possible either due to local melting of the layer and its subsequent cooling or due to its orthogonal realignment (Graph 6') (changes of the direction of its alignment capacity as regards LC) when the area is affected by orthogonal polarized emission.

It should be pointed out that in the latter case when exposure power is commensurable with power exposure in the writing mode we can achieve another thermodynamically stable condition (in temperatures that are less than the layer melting temperature). This condition is high and orthogonally directed against the initial alignment state, so we may regard it as a logical negative unit ":-1". As this takes place, we may delete and write new data at the same time.

The re-writing mode is similar to initial writing (Graph 7).

In our invention all writing and deleting operations in the given photosensitive alignment and registering layer are performed by supplying voltage to all out-of-focus layers that are located before the given layer, including the layer itself (for LC compositions with positive dielectric anisotropy). In the other option we may supply voltage just to the given layer (for LC compositions with negative dielectric anisotropy). In other words, data reading is possible either when we supply electric voltage to all data layers with the exception of the layer that is being read (first option), or we may supply voltage just to the layer that is being read (second option).

In the reading mode our invention does not make use of the volume modifications in anisotropic optical properties of the given alignment and registering layer 912 (922), which is capable of performing two functions. However, they may be used for quality control and for correction of already recorded data or the data that is being written. In these media it is possible to do it in real time and after recording has been completed. These operations are performed by adjusting time and (or) space parameter and the distribution of emission intensity and writing pulse energy. We may also adjust the recording device polarization or the optical system of the recording device.

Indeed, photo-induced anisotropy in photoanisotropy materials occurs directly in the process of exposure, as the time that is required for these photo-alignment and photochemical processes never exceeds one hundreds of a microsecond. The occurring two-beam refraction (TBR) is also guided to
the transparent area, which is the area that is located outside the specter area of photosensitive registering layers.

All this allows us to control data that is being written with the help of this non-destructive method, as we use emission that is not photoactive, for instance, we may employ He-Ne ($\lambda = 632.8$ nm) or semiconductor ($\lambda \sim 700$ nm) lasers in real time or after writing has been completed.

In the exposure phase when we use polarized photoactive emission in Layer 912 (922) in the reading mode we may observe the emergence of fluorescent data pit precursors that may take the shape of hidden molecular alignment on the surface and may present a three-dimensional anisotropic phase (two-beam refractive) modulated pattern positioned against an isotropic background. Due to the fact that the layer is very thin we observe one-to-one correspondence between the degree of orderly molecular alignment both within the layer and on its surface (912) (922).

We may control the quality of writing by non-photoactive, polarized emission through converting the hidden three-dimensional pit precursor pattern to a three-dimensional modulated pattern with the help of a polarizing analyzer, positioned between the exposed registering layer and a photodetector.

Space distribution of reading emission intensity ($I(x, y)$), after it has passed through the hidden pit precursor pattern and through the analyzer, may be determined using the value of the two-beam refraction (TBR) guided in the process of writing:

$$I(x, y) = I_0 x \sin^2 \left(\pi \Delta n(x,y) d/\lambda \right) = \text{Const} \times (\Delta n(x,y))^2$$

(3)

Where:

$$\Delta n(x,y) = \Psi(H(x,y)) - \text{TBR space distribution directed to a precursor of the pit that is being formed and affected by activating emission with space distribution of energy H(x,y)};$$

- $d$ - registering layer thickness
- $\lambda$ - wavelength of reading emission
- $I_0$ - intensity of reading emission that reaches the data carrier;
- $\text{Const} = I_0 x (\pi d / \lambda)^2$, and
- $X$, $Y$, - three-dimensional (space) coordinates on the plane of the registering layer location.

We may also assume that the optical axes of both polarizer and analyzer are orthogonal, while the optical axis in the corresponding TBR registering I-layer, directed at an $\Psi$ angle will be positioned at a 45° angle in relation to those axes.
To simplify understanding of Formula 3 we may assume that due to the fact that the registering layer is very thin, its absorption at the wavelength of activating emission is also very small and its intensity within the layer depth Z and, consequently, its TBR are similar, while the value of phase delay (φ) is also very small (φ = πΔn(x,y)d/λ).

Fig. 11 and 12 give a schematic idea of two possible options for data writing using the proposed technology for control and correction of the quality of hidden information pit pattern within the layer.

The option in Fig. 11 ensures control and correction of a bit-by-bit data writing through bit-by-bit reading of the hidden pattern of recorded information using the DRAW technology (direct reading after writing) in real time. In the process of writing Modulator 1103 modulates Laser beam 1101, which has been polarized by Polarizer 1102 and is being recorded by Record signal 1104.

The modulated recording beam (1105) is focused by a lens (objective lens) (1106) onto the registering layer (1107) of the multilayer data carrier (1108). The device uses a special beam scanning method, where each pit is exposed individually. This method does not require any photo template. To obtain the set data pattern the invention uses a special programming device to scan the beam.

Within Layer 912 (922) in its exposed areas we may observe successive appearance of precursors of fluorescent information pits and the pattern acquires the shape of a two-beam refraction and space modulated pattern which may be observed against an isotropic background. The TBR value and its space distribution in the hidden pattern (precursor space topology) can be determined using the value and space distribution of the recording pulse energy. The latter is determined with the help of a corresponding modulation code (1104) and depends on the quality of the lens focus.

The hidden image of these phase precursors of information pits may be read in real time in the bit-by-bit mode by focused photo non-active laser emission (1110) (for example by He-Ne laser (1109) whose emission wavelength equals 632.8 nm). To do this the playback beam (1110) is transformed into a linear polarized beam by a polarizer (1111). When it passes through a dichroic mirror (1113) it is focused by the lens (1116) on the focusing area of the writing beam (1105) that writes on the registration layer (1107). Having passed through the micro-area of this layer the linear polarized playback beam (1112) that is capable of carrying the written hidden anisotropic pattern of the fluorescent pit precursor is transformed into an elliptically polarized beam (1114), which partially goes through the analyzer (1115). The lens (1116) projects the visualized image of this fluorescent pit precursor onto a photoelectric detector (1117), which emits an electrical signal (1118). This signal is processed by computer and then reaches the exposure device control unit (not shown in Figure 11).
Thus, the proposed method of precision measuring of parameters of the hidden image of fluorescent information pits precursors, which is formed in real time, allows us to get feedback through adjusting the power and polarization of writing emission, exposure time and also the quality of intensity distribution in the exposure beam through correction the lens focus (1106).

Figure 12 depicts another possible variant of employing the proposed method where a CCD camera (1119) is used as a photo-detector (1117). In this case we can selectively or, if necessary, completely control the quality of space topology of hidden patterns of the fluorescent information pits predecessors in the registration layer of the multilayer data carrier (1120) as soon as writing is completed. The reading diagram in Figure 12 is similar to the diagram shown in Figure 11, it also includes a polarizer (1111) and an analyzer (1115) but the lens (1106) instantly reads the entire hidden pattern in the registering layer, which is projected by the lens (1116) to the CCD camera (1119) location plane. This possibility of analyzing hidden patterns allows us to create optimal conditions for forming registration layers, for instance of the ROM-type, in the combined multilayer data carriers.

The proposed technical solution of designing the fluorescent data carrying layer as a multi-component structure that constitutes a thin electrically controlled liquid crystal cell with at least one initially patterning (for the ROM-type systems) or photo-anisotropic photosensitive (for the WORM- or RW-type systems) alignment layer allows us to distribute functions among various components.

When we do the writing in the WORM- or RW-type systems we write in one of the aligning layers which also serves as registration layer. Here data is written thanks to surface space modulated alignment ability as regards the LC layer, in other words, we are able to form a photo-patterning, photoaligning layer.

In the reading mode we use the guest-host LC matrix with anisotropic absorbing photo-chemically stable fluorescent host substances regardless of the carrier type (ROM-, WORM-, or RW-type). This distribution of functions in the writing and reading modes in the combined fluorescent liquid crystal data carriers of the WORM- or RW-type drastically simplifies the requirements for fluorescent compositions used in these devices. The use of photochemically stable fluorescent substances in such systems allows, for example, to completely solve the problem of emissivity storage of the currently existing fluorescent data layers in the WORM-photosensitive systems based on bimolecular photochemical reactions and employing naturally fluorescent substances or whose photoproducts would be fluorescent. This is related to emissivity thermal chemical or diffusion processes that may occur in them. These processes create a trail made of fluorescent molecules; they also create background fluorescent emission in the reading mode or diminish the intensity of the fluorescent signal due to emissivity decomposition of the initially fluorescent dye.
As it was mentioned earlier, the RW-photosensitive systems based on photo-chrome reactions have the following disadvantages: reverse emissivity processes and a possible low “writing – deleting – writing” cycle due to photodestruction of photochrome molecules.

In our invention we also propose another option of multi-layer combined LC optical systems with the ROM-, WORM- or RW memory type. Instead of fluorescent anisotropic absorbing substances this option employs non-fluorescent, photochemically stable substances that also become anisotropic absorbing substances at the set reading wavelength. These substances are used as additives to host molecules. For this purpose we need to select non-fluorescent substances that can be well-diluted in liquid crystal compositions. Their molecules have a rod-like or disc-like form and their long-wave oscillator is positioned along their long axis or across it. These substances are employed in LC screens, which operate on the guest-host principle. We can also use anisotropic dyes with negative dichroism.

In this case all the above referenced optical memory designs (Figures 3-6, 7-9, 11, 12) and data writing, reading and deleting operations (Figures 7, 10) remain the same. But reading is done either by detecting the quantitative difference of reading emission intensity in the information pits and background locations or by measuring the presence or absence of the anisotropic properties (polarization degree) of reading emission, or measuring differences in direction of its optical axis.

It should be pointed out that this reading mode could be also used in the fluorescent systems of optical memory that were described above.

Another option of the proposed solutions is related to the use of the LC compositions containing no anisotropic fluorescent or non-fluorescent additive molecules. In this case the composition of multilayer data layers also remains the same.

Reading is made possible by positioning the multilayer data carrying structure between the two polarizers as it is shown in Figure 11 and 12. In this process the polarizer’s optical axis should be orthogonal to the analyzer’s optical axis.

Emission intensity which is read from data layer- I and which goes through the analyzer in the information pit \( I_{\text{in}} \) location area and in the background \( I_{\text{back}} \) area can be written down in the following way:

\[
I_{\text{in}} = I_0 \cdot \sin(2a_{\text{in}}) \cdot \sin^2(\pi \Delta n_{\text{in}} \cdot d_{\text{in}} + \Delta n_{\text{lc}} \cdot d_{\text{lc}})/\lambda),
\]  

(4)
\[ I_i^{\text{back}} = I_0 \cdot \sin(2\Delta n_i^{\text{back}} \cdot \sin^2(\pi (\Delta n_i^{\text{back}} \cdot d_i^{\text{back}} + \Delta n_i^{\text{lc}} \cdot d_i^{\text{lc}})/\lambda)) \]

where \( I_0 \) is intensity of the reading emission that reaches layer \( i \) of the multilayer data carrier;
- \( \Delta n_i^{\text{pit},\text{back,lc}} \), \( d_i^{\text{pit},\text{back,lc}} \) - DLP value induced by writing emission in the information pit location area in the alignment and registering layer \( i \) and in the adjacent LC layer \( i \); and their thickness accordingly;
- \( \alpha_i^{\text{pit,back}} \) - angles between the direction of the polarizer's (analyser's) optical axes and the DLP optical axis in the information pit and background \( I \)-data layer location area respectively; and
- \( \lambda \) is reading emission wavelength.

To get maximum contrast equal to 1 the angle \( \alpha_i^{\text{pit}} \) towards the polarizer should be equal to 45°, while the angle \( \alpha_i^{\text{back}} \) in relation to the polarizer should be equal to 90° (or 0°). In this case the \( I_i^{\text{back}} \) value = 0 and \( I_i^{\text{pit}} = I_0 \cdot \sin^2(\pi \Delta n_i^{\text{lc}} \cdot d_i^{\text{lc}}/\lambda) \) (with \( d_i^{\text{back}} << d_i^{\text{lc}} \)).

Another way of writing data in these combined multilayer optical memory systems of the WORM type that might have or not have a fluorescent or anisotropic absorbing substance in the LC composition is photo-thermal writing with the help of misalignment of the surface of the aligner. For this purpose we may use absorbing writing emission and mechanically rubbed layers or Langmuir-Blodgett layers, the layers coated with slanted spray and some other layers. To increase absorption in the writing mode we can also add some substances that can absorb this emission, they may also be added to the LC layer. These can be either thermal-chrome or photochrome substances. One can also use electric chrome organic or non-organic substances of the \( \text{VO}_2 \)-type as well as electric field chrome substances.

Thus, our proposal allows to create a new structure of multilayer combined liquid crystal optical memory system of the ROM-, WORM- or RW-type and ways of writing and reading data to (from) it. In our system we are able to electrically control the absorbing and emitting ability of fluorescent molecules dissolved in the liquid crystal matrix of the data carrying layers. In its turn, it also allows to eliminate, partially or completely, fluorescent cross talk from adjacent data layers while reading both in the pit-by-pit and page-by-page mode.

In addition, we also have one more option of electrical control (and, if necessary, smooth control) of intensity of the fluorescent data signal while intensity of reading emission remains unchanged. In particular, reduction or complete elimination of fluorescent cross talk allows us to minimize the distance between the layers. This, in its turn, allows us to collect more light from reading fluorescent emission and to simplify the design of the reading optical head, as we are able to diminish parasite aberration distortions and increase the number of data layers in the carrier. In addition, the proposed solution expands the area of possible applications, and this is true not only of various non-linear but
also linear photochemical or photo-physics mechanisms of single or multiple data writing. It also allows employing the same emission source for writing, reading and deleting data in such a carrier.

The use of photo-anisotropic materials based on photochemically stable anisotropic absorbing and non-fluorescent substances as registering media that also play the role of photo-patterned and photo-aligning layers allows practical application of the re-writable multi-layer memory system with fluorescent data reading.

This invention may be illustrated with the following examples of component composition and structure of the proposed guest-host liquid crystal data-carrying layer.

Example 1. Fluorescent data carrying layer of the ROM type where the spacer also serves as data carrying layer.

Fluorescent substance – 1.4 – bis(N,N-diphenylaminophenyl-1,3,4-oxadiazy)benzene or 1,8-naphthalene-1,2 benzimidazole.

Liquid crystal – 4 -octyloxy 4' -cyanobiphenyl (8OCB).

Example 2. Fluorescent data carrying layer of the WORM type.

Photo-aligner – para-metoxy polyvinilscinnamate.

Fluorescent substance – dye # 1 (Fig. 13)

Liquid crystal – LCM 440 (NIOPiK, Russia).

Example 3. Fluorescent data carrying layer of the RW type.

Photo-aligner – Dye # 2.

Fluorescent substance – Dye # 1.

Liquid crystal – LCM 807 (NIOPiK, Russia).

Example 4. Data carrying layer of the RW type with dichroism properties dye.

Photo-aligner – Dye # 2

Liquid crystal - LCM 807.

Dichroic dye – Dye # 3.

Example 5. Data carrying layer of the RW type without dyes.

Photo-aligner – Dye #2.

Liquid crystal – LCM 440.
The above referenced examples just illustrate the proposed new structure of the multilayer combined fluorescent liquid crystal optical memory system and the methods of data writing and reading to / from it. They shall not restrict our claims, described in the following patent formula.
What is claimed is:

1. Multilayer combined fluorescent liquid crystal optical data carrier, comprising:
   - numerous data carrying layers located in parallel planes;
   - the data layers are located on the same pad and divided with transparent intermediate layers;
   - each of the data carrying layers is manufactured as a multi-component structure that constitutes a thin electrically controlled liquid crystal cell, made of two similar optically transparent electrodes that are made as solid layers or as a system of two mutually orthogonal strips that are coated with at least one alignment layer and are divided by spacers, the space between them is filled out with the guest-host liquid crystal composition and photochemically stable anisotropic absorbing fluorescent substances that are used as host substances.
2. Data carrier according to claim 1, wherein optically transparent electrodes are applied to both sides of glass or polymer intermediate layers – preferably optically isotropic and transparent for all writing, reading, fluorescent and deleting emissions, at least one side of the intermediate layers has a smooth surface, while the other side contains tracks in the form of small pits.
3. The data carrier according to claim 1 and claim 2, where the refraction indexes of all data carrying and intermediate layers as well as the guest-host LC composition in the homeotropic state (or in the planar state, depending on its nature and writing mode and (or) reading data) are the same or close to each other at the wavelengths of writing fluorescent (data carrying) and reading (which excites it) and deleting emission.
4. The data carrier according to claim 1, wherein the data carrying layer is made in the form of multilayer interference antireflection filter for the wavelengths of writing, fluorescent (information carrier) and exciting it (reading) and deleting emission.
5. The data carrier according to claim 1, wherein the LC layer thickness has a volume commensurable with the minimal size of the information carrying pit which is formed in it.
6. The data carrier according to any of the foregoing claims, including substances that can dissolve in liquid crystal compositions and are highly fluorescent as they emit a high number of photons (quanta), as they are photochemically stable substances that become fluorescent in the set specter, these substances have molecules that aligned in tough, rod-like or disc-like clusters, and their long-wave absorption oscillator is directed along their long axis or across the axis.
7. The data carrier according to claims 1 and 6, including fluorescent substances that have been selected from the photochemically stable compositions that comprise the group of aromatic carbohydrates and their derivatives, such as multicore condensed aromatic carbohydrates and their derivatives; also those carbohydrates that include arilethylene and arilacetylene groups and their derivatives (1,2- diariletylenes, diarilpolyenes, stilbene functional replacements and...
1,4-distyrylbenzol replacements, etc) and polyphenyl carbohydrates; compositions containing five- (furans, thiophens, pyroles and their derivatives, etc.) and six member molecules (one or two nitrogen atom compositions or one or two oxygen atom compositions, etc); heterocyclic compositions; compositions containing the carbonyl group (coumarins and carboxenated substances, anthron and aromatic acids derivatives; oxazol-5 replacements, indigoids and thiindigoids, quinones, etc); naphthalic acid compounds; and also complex compounds of metals with organic ligands and organic dyes of the xanthene group, acridine group, oxazine group, azine group, periline group, terilene group, vialonhthrene group, cyanine group, phtalocyanine group, porphyrine group, etc.

8. The data carrier according to claims 1 and 7, including nematic, smectic or cholesteric liquid crystals or their mixtures with other substances to obtain liquid crystals.

9. The data carrier according to claim 8, in which liquid crystals and fluorescent substance have been mixed in a molar ratio between 1: 0.01 and 1: 0.8.

10. The data carrier according to claim 1, in which photochemically stable, anisotropy absorbent fluorescent materials have covalent connections with the molecules of the substance with liquid crystal properties.

11. The data carrier according to claim 1, including liquid crystal substances as photochemically stable, anisotropy absorbent fluorescent materials as they are capable of fluorescing when they are affected by emission and absorb it.

12. The data carrier according to claim 1, including at least one alignment layer that can be manufactured by one-way mechanical rubbing of polymer films, Langmuir-Blodgett films or slanted spraying or made with the help of non-contact photo alignment method that works well with photoanisotropic materials.

13. The data carrier according to claim 1, including a spacer positioned between smooth (both sides) and equally thick dividing layers. This spacer has a three-dimensional patterned appearance and ensures the necessary thickness of the guest-host liquid crystal composition, serving at the same time as a data layer of the ROM type.

14. The data carrier according to claims 1 and 13, including a three-dimensional patterned spacer that may be fabricated from a photosensitive polymer or positive or negative photoresistor with application of lithography or laser scanning.

15. The data carrier according to claims 1 and 13, including a three-dimensional patterned spacer serving at the same time as a data layer of the ROM type, the spacer being molded by injection-compression molding technology or the 2P-process on the basis of photopolymerizable composition and positioned right on one of the surfaces of the dividing layer.

16. The data carrier according to claims 13 and 15, which may not have one or both alignment layers.
17. The data carrier according to claim 1, in which one of alignment layers also serves as a photosensitive layer registering layer for the ROM-, WORM- and RW types, said layer having made of photo-anisotropic material, which does not dissolve in the guest-host liquid crystal composition.

18. The data carrier according to claims 1 and 17, in which the minimal thickness of the photosensitive alignment and registering layer may be as thick as one monomolecular layer.

19. The data carrier according to claim 1, in which tracking regions that guide beams for recording, reproduction or erasing operations are formed right in the photosensitive alignment and registering layer manufactured from photoanisotropic material.

20. The data carrier according to claims 1 and 17, in which the energy value of adhesion between liquid crystals molecules and the molecules of the photosensitive alignment and registering layer surface can be controlled by the energy of its exposure to polarized emission.

21. The data carrier according to claim 1, in which the photosensitive alignment and registering layer of the WORM type is fabricated from photo-anisotropy materials based on monomolecular irreversible photochemical reactions or bimolecular photochemical reactions, like diacetylene derivatives or polyvinilcynnarnates.

22. The data carrier according to claim 1, in which data layers may be of the following types: CD- or DVD-read only memory (ROM), write once read many (WARM), rewritable (RW) or their mixed types in a variety of optical discs, cards or tapes.

23. The data carrier according to claims 1 and 22, in which photochemically stable, anisotropically absorbent non-fluorescent substances have been introduced into a polymer matrix or they may be used as a homogeneous single substance film with a small number of special additives that serve to improve their film-forming properties.

24. The data carrier according to claim 1 and 22, in which the data layer is designed as a multi-component structure and constitutes a thin electrically controlled liquid crystal cell with at least one alignment layer.

25. Device for writing, reading and deleting data on (from) the fluorescent multilayer data carrier, that includes:

- multilayer combined fluorescent liquid crystal optical information carrier containing numerous data carrying layers of a multi-component structure, that constitutes a thin electrically controlled liquid crystal cell comprising of two similar, optically transparent electrodes manufactured as solid layers or as a system of two mutually orthogonal strips coated with at least one aligning layer and divided by spacers, the space between the spacers is filled out with the guest-host liquid crystal composition, with stable photochemical anisotropic absorbing fluorescent substances used as host substances;
sources of electromagnetic emission with wavelengths for optical or thermal optical writing, optical reading and optical or thermal optical deletion of information stored on the data carrier;

- polarizing optical means to set polarizing characteristics of writing, reading and deleting emissions;

- optical means to form the set space configuration of electromagnetic beams that write, read and deleting information in the pit-by-pit or page-by-page mode;

- photo-receiving means ensuring pit-by-pit or page-by-page photoelectric detection of intensity of data carrying fluorescent emission that is being read and (or) its polarization characteristics (polarization degree and direction of the prevalent alignment of partially polarized emission) with its subsequent transformation into data carrying electrical signals;

- optical electronic means to ensure quality control and correction of written data, capable of sending a feedback signal of writing mode correction either in real time or as soon as writing has been completed; and

- means to supply electric voltage to any given pair of solid or strip electrodes to control absorbing and fluorescent capacity of the guest-host liquid crystal composition located between them.

26. Device according to Claim 5, in which the absorbing spectra of the photosensitive aligning and registering layer made of photo-anisotropic material and the spectra of the multilayer data carrier fluorescent substance partially or completely overlap.

27. Device according to claims 25 and 26 including an emitting source with the same wavelength but with different time, energy and polarization parameters of optical emission to write, read, delete and correct the quality of the data that is being written on the multilayer optical carriers of the WORM- or RW-type.
Fig. 5
(Prior Art)
Fig. 7