Abstract: The present invention relates to a re-recordable volumetric data store (1) comprising at least one storage level (3; 4; 5...) formed with an array of receptor cavities corresponding to an array of storage locations. A fluid store for a fluid medium is provided, the fluid medium being capable of exhibiting a change in at least one optical property thereof in response to a predetermined stimulant. A septum means is disposed between the fluid medium and the array of receptor cavities. An urging means can encourage the fluid medium to flow through said septum means into selected storage locations of said array in dependence upon a pattern of digital information to be stored in said array and can encourage said medium to return through said septum from at least some of said selected storage locations to said fluid store prior to the storage of a replacement pattern of digital information in said array. In a further embodiment, each cavity contains a medium capable of exhibiting a change in at least one optical property in response to the state of orientation of its molecular structure.
Published:

- With international search report.
- Before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments.

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.
RECORDABLE VOLUMETRIC DATA STORE

This invention relates to re-recordable volumetric data stores, in particular multi-level digital stores.

In co-pending patent application No. GB9806209.4, (hereinafter referred to as "the earlier application") there is described a high capacity three-dimensional, optically-addressed storage device comprising multiple juxtaposed and substantially planar storage levels from which digital data stored in any given level can be rapidly and reliably retrieved despite the presence of data stored in other layers and, in particular, the extreme proximity of data stored in neighbouring levels.

In order to retrieve stored information, interrogating radiation is projected through the device orthogonally to the planes of the storage levels, possibly in a flood beam but preferably in a beam defined by means of an electronic mask, such as a TFT array or a liquid crystal device. In any event, the interrogating beam is repeatedly refocused during its passage through the device to reduce retrieval errors associated with beam spreading.

A particular level to be read is selected by its illumination, within its plane, with one or more beams of selecting radiation. The selecting radiation stimulates optically sensitive material deposited at selected digital storage locations in the layer, so as to cause that material to absorb the radiation of the interrogating beam significantly more strongly than it does in the absence of the selecting radiation.
This invention relates especially, though not exclusively, to data stores such as that described above, and it is one object of the invention to improve such stores with regard to their in-situ recordability.

According to the invention from one aspect there is provided a re-recordable volumetric data store comprising at least one storage layer formed with an array of receptor cavities corresponding to an array of storage locations, a fluid store for a fluid medium capable of exhibiting a change in at least one optical property thereof in response to a predetermined stimulant, adjacent said storage layer, septum means disposed between the fluid medium and the array of receptor cavities and means for encouraging the fluid medium to flow through said septum means into selected storage locations of said array in dependence upon a pattern of digital information to be stored in said array and for encouraging said medium to return through said septum from at least some of said selected storage locations to said fluid store prior to the storage of a replacement pattern of digital information in said array.

Preferably, said medium is responsive to magnetism, and said urging means comprises means for generating magnetic forces locally to said cavities. This permits the medium to be encouraged to flow through said septum under the influence of reliable and spatially controlled forces; it being further preferred that said urging means comprises means for generating respective magnetic forces individually for each cavity.

Preferably, said urging means comprises first urging means encouraging said medium to flow in one direction through said
septum and a second urging means encouraging said medium to flow in the opposite direction through said septum. This permits the medium to be positively urged as to movement in both directions and moreover provides the facility for providing a retaining force in one or other or both directions, should such retention prove necessary.

In a preferred embodiment of the invention, said urging means comprises photovoltaic material and means for selectively illuminating respective regions of said material. The use of photovoltaic material readily permits the accurate generation of localised magnetic forces in response to the selective application to the material of light. This is particularly advantageous when the store is intended to be read and/or written to by the application of light, as common components may be used.

Preferably, where photovoltaic material is used, it is provided in an array of reservoir locations disposed in one-to-one relationship with said storage locations. This permits accurate and well controlled transfer of said medium through said septum. In a preferred arrangement, said photovoltaic material is disposed in first and second identical arrays disposed to either side of said storage locations, giving one-to-one correspondence between the said storage locations and urging means on both sides thereof.

In an alternative embodiment, said urging means comprises thermal energy, in which case said medium is preferably rendered selectively absorbent of an energy source capable of heating said medium. Localised heating at a given location can be readily achieved by means of light beams constrained to be coincident at that location.
Preferably said septum comprises a layer or coating of microporous material. This enables the flow of said medium to be accurately controlled.

According to the invention from a further aspect there is provided a re-recordable volumetric data store comprising at least one storage layer formed with an array of pixel cavities corresponding to an array of data storage locations; each cavity containing a medium capable of exhibiting a change in at least one optical property thereof in response to the state of orientation of its molecular structure, individual control means disposed adjacent each of said pixel cavities and capable of controlling the orientation of the molecular structure of the medium therein, in dependence upon a pattern of digital information to be stored in said array, and means for selectively energising some at least of said control means to reorientate the molecular structure of the medium in the associated pixel cavities, thereby to effect storage of a replacement pattern of digital information in said array.

Preferably, the orientation of the molecular structure of said medium is responsive to magnetism, and said control means comprises means for generating magnetic forces locally to said cavities. This permits the orientation of the medium's molecular structure to be adjusted locally under the influence of reliable and spatially controlled forces.

Preferably, said control means comprises, for each pixel cavity, respective first and second control components, each capable of encouraging the molecular structure of said medium to adopt a selected differential orientation. This permits the medium to be positively driven into one of two selected
orientation conditions and moreover provides the facility for providing a retaining force for one or other or both orientations, should such retention prove necessary.

5 In connection with the immediately preceding paragraph, it is to be noted that one of the aforesaid orientations could comprise a general disordering or molecular alignment. Thus, the two conditions could comprise, respectively, alignment and non-alignment of molecules or molecular chains. 10 Preferably, however, the two conditions comprise respective but significantly different molecular alignments, one possibly in the z-direction and the other in the x-y plane.

In any event, the objective is to create two alignments which affect the transmission of light to reliably distinctive extents. Colouration can be used to enhance the differential transmission characteristics if necessary.

In a preferred embodiment of the invention, said control means comprises photovoltaic material and means for selectively illuminating said material. The use of photovoltaic material readily permits the accurate generation of localised magnetic forces in response to the selective application to the material of light. This is particularly advantageous when the store is intended to be read and/or written to by the application of light, as common components may be used.

Preferably, where photovoltaic material is used, it is provided in paired arrays of reservoir locations; a respective reservoir location of each pair being disposed in one-to-one relationship with each of the respective pixel cavities comprising said storage locations. This permits
accurate and well controlled molecular orientation of said medium in accordance with data to be stored. In a preferred arrangement, said photovoltaic material is disposed in first and second arrays, displaced respectively vertically and laterally of said storage locations, giving one-to-one correspondence between each of the said storage locations and a respective pair of the control components of said control means.

In preferred embodiments of the invention, the store may conveniently comprise a plurality of substantially planar storage layers stacked with their storage planes juxtaposed and parallel to one another and spaced apart in the direction normal to their planes, and each of said storage layers may be associated with a respective collimation layer capable of collimating light transmitted through said store in said direction normal to the planes of said storage layers; the collimation layers being interleaved with the storage layers.

This provides an arrangement capable of high capacity storage of data whilst retaining highly accurate and rapid read-out capabilities.

Further, a store so configured can usefully be constructed so that said control means includes a respective array of control cavities formed in each of said collimation layers, and so that said control means further includes a respective array of control cavities formed in said storage layer. This provides for compact and accurate location of the various inter-related components.

In circumstances such as those described in the immediately preceding paragraph, it is further preferred that each pixel
cavity is associated with two respective control cavities; one in said storage layer and one in the associated collimation layer.

In order that the present invention may be clearly understood and readily carried into effect, certain embodiments thereof will now be described, by way of example only, with reference to the accompanying drawings, of which:

Figures 1 and 2 show, in perspective view, an optical data store as described in the earlier application and to which the present invention may advantageously be applied;

Figure 3 shows schematically a portion of the store of Figures 1 and 2, modified to illustrate an operating principle of the invention;

Figure 4 shows, in fragmentary detail, a first embodiment of the invention;

Figure 5 shows, in similar view to Figure 4, a second embodiment of the invention;

Figure 6 shows schematically and on an enlarged scale a portion of the store of Figures 1 and 2, modified to illustrate a further operating principle of the present invention; and

Figure 7 shows a third embodiment of the present invention.

None of the drawings is to scale in any dimension.

Referring now to Figures 1 and 2, the data storage device
shown therein comprises principally a data storage body 1 which co-operates with a detector arrangement 2. The body 1 includes several individual and independent storage levels such as 3, 4 and 5; each storage level comprising a laminate consisting of an upper layer such as 6 and a lower layer such as 7; both layers being formed of a suitable optical medium such as polycarbonate. The two layers are bonded together, for example by means of a suitable optical cement, to form the level 3.

In accordance with one technique described in the earlier application, data to be stored are recorded, prior to assembly of the device, in the lower layers such as 7 of each storage level, for example by pressing indentations into the surface thereof in the same way as compact discs are pressed, at each location where it is desired to store a binary zero, and an optically active material, such as silicone mixed with a slightly opaque coloured dye, is applied to the indented surface so as to enter each of the indentations. The upper layer such as 6 is then laminated to the lower layer and secured thereto in a manner permitting good optical transmission in a direction substantially normal to the planes of the layers. No pits are formed at locations where it is desired to store binary "1"s.

The principal tasks of the material of the upper layers such as 6 of each level are to collimate light passing therethrough in a direction substantially normal to the layer planes, and to pass such light without substantial attenuation. To these ends, the upper layers 6 are formed of highly transmissive material such as polycarbonate, acetate or glass, and are either processed or fabricated so as to align the molecules of the material in a direction normal to
the layer planes or are constructed of optical fibres or other optical ducting components orientated to achieve the desired effect. Alternatively or additionally, one or more arrays of microlenses, may be used to assist in such collimation.

The lower layers such as 7 of each storage level are at least notionally delineated into an array of resolvable elements, or pixels, each of which can be caused, in this example, to assume an optical condition indicative of either a digital "0" or a "1", depending upon the condition impressed upon its surface (i.e. pit and no pit, respectively) and therefore, and importantly, upon the presence or absence of the optically active material. Typically, a data "0" is indicated by a pit impressed into the surface of layer 7 (and thus by the presence of the optically active material in the pit). The upper layers such as 6, of course, can be (and preferably are) uniformly constructed over their entire extent.

In the drawings, the plane of each layer extends in an x, y co-ordinate plane and the aforementioned direction normal to the layer planes thus extends in the z-direction. This convention will be adhered to for the remainder of this specification. It will thus be appreciated that light incident upon the device 1 generally in the z-direction will be constrained to pass therethrough, without significant lateral spreading in the x,y plane, by means of the operation of the upper layers such as 6, but that the amount of light emergent from the component in that direction and incident on detector 2 may be influenced from pixel to pixel in the x, y plane of any storage level by the information impressed on the lower layer 7 at that level. However, if this principle were adopted simpliciter, the use of multiple storage levels
would be precluded, since the patterns of data recorded in overlying levels would interfere.

As provided in the earlier application, therefore, the pattern of data recorded at any given level is rendered capable of influencing so-called interrogating light, travelling in the z-direction, only when the data storing layer (such as 7) at that level is illuminated with light of a particular wavelength, range of wavelengths or combination of wavelengths. This is achieved by selectively illuminating at least the data storing layer at the chosen level from one or more directions with so-called selecting energy consisting of light of appropriate characteristics to cause the optically active material deposited in the data pits of the lower layer 7 at the chosen level to temporarily assume a condition that will block the interrogating light.

Thus, pixels where there are no pits are always transmissive of the interrogating light and pixels having pits filled with optically active material are also transmissive to that light unless the optically active material is illuminated by the aforementioned selecting energy. By this means, any individual level, or portion of a level, depending on the nature and configuration of the selecting energy, can be caused to influence the interrogating light, in accordance with the pattern of recorded data recorded in its data storing layer such as 7, whilst the remainder of the device merely acts as a fairly uniform transmitter of the interrogating light.

Figure 2 shows a light source 8, which may produce white light or light of a selected spectral characteristic, disposed to irradiate an electronically controllable shutter
9. The shutter 9 typically comprises a thin-film transistor (TFT) screen parallel to and aligned with the storage levels of the device 1 and conveniently disposed in contact with, or closely proximate to, the upper layer 6 of level 3.

The arrangement is such that there is a one-to-one relationship between the apertures which can be selectively opened in the shutter 9 and the pixels in the lower layer 7 of each level of the device 1; the layers having identical pixel formats. Moreover, corresponding pixels at different storage levels are accurately registered and juxtaposed. Thus, the opening of a single aperture in the shutter 9 permits light from the source 8 to enter the component 1 at the appropriate position in the x-y plane and to travel in the z-direction through corresponding pixels in each of the levels 3, 4, 5. Light emergent from the last level of the device 1 (i.e. the level farthest, in the z-direction, from the shutter 9) is incident on a light detector 10 which provides an electrical output signal indicative of the amounts of light incident from time to time thereon, to a processor 11 which is also supplied with timing information indicative (inter alia) of the timing of the electronic control signals applied to the shutter 9 and thus effectively of the addresses of the pixels of the storage levels in the device 1 through which light detected at any time by the detector 10 has passed.

By the foregoing means it will be appreciated that the light from source 8 can effectively be scanned in the x-y dimension over the upper surface of the top level 3 of component 1, thereby to project the light in sequence, in the z-direction, through corresponding pixels of the various storage levels of the device 1 and on to the detector 10.
In the absence of selecting energy to the device 1, the light incident upon detector 10 during a complete cycle of operation of the shutter 9 remains substantially constant, despite variations that will inevitably occur in the 5 combinations of data recorded in corresponding (juxtaposed) pixels of the storage levels of device 1 from place to place, as the optically active material in the data pits has not been rendered capable of influencing the light from source 8.

The shutter 9 and/or an additional, directly associated component (not shown) may if desired be caused to contribute to (or wholly impose) a predetermined spectral characteristic on the light from source 8 and, if the light from source 8 has a particular spectral characteristic imposed thereon, the detector 10 is preferably rendered selectively responsive to light of that characteristic.

In general, the electronic control of the shutter 9 is such as to cause the light from source 8 to scan in a regular raster format, one pixel at a time, over the device 1; the actual scanning regime used being communicated to the processor 11, so that the necessary correlation can be achieved between the signals output from detector 10 and the z-direction paths through device 1 to which they relate.

Thus, the arrangement is such as to scan light from source 8 over the component 1 so as to pass in sequence, in the z-direction, along paths through respective groups of overlying pixels of the various storage levels of component 1, and the light emergent from the component 1 along each of the paths is detected by detector 10. Electrical signals corresponding to the detected light for each path are applied to the processor 11, typically a microprocessor.
In order to influence the optically active material deposited in the data pits associated with binary "0"s, individual storage levels are selectively irradiated by the selecting energy which comprises a combination of light of two different colours incident on the selected storage level via respective electronically controlled shutters 12 and 13. The rectangular configuration of the device 1 renders it convenient to have one of the shutters (12) interact with light from a source 14, incident from the x-direction, and the other shutter (13) interact with light from a source 15 incident from the y-direction.

All of the comments made above in relation to the imposition of spectral characteristics on the light produced by source 8 apply, mutatis mutandis, to the sources 14 and 15, though it will be appreciated that light from all three sources as incident on the component 1 will be different. In any event, the detector 10 and/or the processor 11 will ideally be desensitised to light bearing the spectral characteristic applied to the light from sources 14 and 15.

The combination of light incident in the x-y plane on the edge of a selected storage level of the device 1 via the shutters 12 and 13 respectively is such as to cause the optically active material in the data pits in the lower layer, such as 7, of the selected level to temporarily become absorbent and/or reflective of the interrogating radiation from source 8, incident on the component 1 via shutter 9. Thus, for example, if the shutters 12 and 13 are such as to permit light from the sources 14 and 15 respectively to irradiate the entire extent of the selected storage level (or at least the entire data storing layer, such as 7, thereof) in their respective dimensions, the optically active material
in all of the data pits at that level will be rendered absorbent and/or reflective of the interrogating radiation from source 8. During a complete cycle of operation of the shutter 9, therefore, scanning the interrogating radiation over the component 1 as described previously, the data stored at the selected level of the device 1 will be read out, detected by detector 10 and recorded with appropriate timing for identification in processor 11.

10 In one specific example of the operation of the device, and assuming the various levels of component 1 to be already recorded with respective data patterns, the selecting energy incident on the edge of a chosen level via shutter 12 is red, and that incident on the edge of the same level via shutter 13 is blue. The optically active material in the data pits representing digital "0"s is made (for example by selection of an appropriately coloured dye) such that it absorbs green light and thus, when simultaneously illuminated by the red and blue lights comprising the selecting energy, the material turns black. In areas of the selected level other than the "0" data pits, there is no optically active material, and those areas of the layer thus appear green because of the presence of the selecting energy.

25 Provided that the interrogating radiation comprising the light incident on component 1 in the z-direction via the shutter 9 is capable of interacting differently with the green and black areas, the data stored in the lower layer, such as 7, of the selected level can be read out, as already described. In particular, interrogating light is chosen that continues unimpeded by the green areas but is substantially absorbed by the black areas; thus the detector 10 receives a light input if a given z-direction path transits a digital
"1" at a selected level, but receives no light input if the path transits a digital "0" in that level.

In an alternative procedure, pits are produced at each pixel, but only those at which zeros (for example) are required are filled with optically active material. In yet another arrangement, pits of respective and different dimensions can be impressed for the two binary data values; in which case the indentations of either or both dimensions can be filled with the aforementioned material. If all indentations are so filled, however, the device must be rendered capable of distinguishing between stored binary values on the basis of the dimensional difference between the respective indentations associated with such values.

The present invention builds upon the configuration described in the immediately preceding paragraph, providing storage levels with an array of storage locations into selected ones of which optically sensitive material can be removably introduced in situ. Thus, referring to Figure 3, which shows schematically the principle of the invention, there is provided, adjacent the lower (data storing) layer, such as 7, at each storage level, such as 3, a reservoir 16 for an optically active fluid 17; the fluid 17 being separated from the regular array of data pits in the layer 7 by a septum 18. The septum 18 may, depending for example, upon its constitution and/or that of the adjacent layers, comprise a film or other discrete layer, or a coating on an adjacent layer. In any event, the septum 18 is of microporous or other suitable construction through which the fluid 17 can be urged to flow in either direction, but through which it does not intrinsically migrate.
Fluid from the reservoir 16 can thus be caused to flow into selected data pits (storage locations) of the data storing layer 7 through said septum 18 in dependence upon a (variable) pattern of digital information to be stored in said pits; and the material can further be encouraged to return through the septum from at least some of said selected storage locations to the fluid store prior to the storage of a replacement pattern of digital information in said array.

The motion of said fluid from and to the selected storage locations, through the septum, may be achieved in various ways without departing from the scope of this invention and, in general, any procedure capable of locally urging the fluid to pass (in either direction) through the septum may be used for writing or erasure of data within the store.

In accordance with a first embodiment of the invention, one example of which will now be described with reference to Figure 4, the localised urging of the fluid 17 through the septum 18 is achieved electromagnetically by means of photovoltaically generated electrical currents.

Referring now to Figure 4, the fragmentary portion of the storage device shown illustrates a structure intended to replace the layers such as 7, 18 and 16 of Figure 3 at each storage level. It will be appreciated that each data storage level, or at least a sufficient plurality of those levels, will retain the upper, z-direction collimating layer 6.

In the construction of Figure 4, the layers 7, 18 and 16, the detailed construction of which will be described subsequently, are supplemented with upper and lower fluid driver layers 20 and 30 respectively. The layers 20 and 30
consist of thin clear film sheets the molecular alignment of which is in the direction parallel to the y-axis to reduce spreading of the selecting light as it passes through. This alignment is simply achieved by stretching the film during extrusion in the direction in which molecular alignment is desired. An alternative embodiment utilises fibre optic strand methodology. The sheets forming the layers 20 and 30 are embossed uniformly with respective, identical arrays of microscopic pits such as 21 and 31. All of the pits, such as 21 and 31, in both sheets are filled with a compound, similar to the compounds used in solar cells (photo-voltaic cells), which generates a small electrical current when it is exposed to light. This compound can, for example, comprise a multi-crystalline silicone solution or a lead chalcogenide in solution, and may be tinted in one colour, for example green, so that is predisposed to filter out all other colours in the light spectrum, so reducing risk of the compound being activated by stray light.

When an individual pit is exposed to light, the solution therein generates electrical current and so creates a localised electromagnetic field around that pit. If the solution in the pit is tinted green, then the irradiation of this pit with green light will generate a current.

Layers 7 and 16 are, in this embodiment, also formed of respective thin, clear film sheets, again, with molecular alignment parallel to the y-axis. Identical arrays of pits are again formed in each film. The pits, such as 71, in layer 7 comprise data pits, while the pits, such as 161, in layer 16 constitute reservoirs, and are filled with a clear viscous liquid compound, for example a solution containing ferric particles. Alternatively, a compound such as indium
tin oxide or similar optically transparent electrical conductors may be used. The solution is tinted so that it will absorb light of a particular wavelength, for example blue. A microporous coating 18 is placed between the data pits of layer 7 and the reservoir pits of layer 16. The layers are then laminated together, with each data pit in layer 7 directly overlying a reservoir pit in layer 16, and separated therefrom only by the microporous coating 18. The viscosity of the solution in the reservoir pits such as 161 permits it to move through the microporous coating 18 into the data pits such as 71, or vice-versa. This movement is caused when the solution is exposed to an electromagnetic field. Once the solution has moved into either a layer 7 data pit or layer 16 reservoir pit, it will remain in this pit even after the field generation ceases and will only change layers when exposed to a field from the other side of the layer. Layer 20 and layer 30 are then laminated to the top and bottom respectively of layer 7 and layer 16, so sandwiching them. Each pit in layer 20, and its counterpart 20 in layer 30, is situated adjacent a respective data pit in layer 7 and a respective reservoir pit in layer 16. In other words, four pits are closely juxtaposed at each pixel location of the relevant storage layer.

In this example, the storage device is illuminated, as before, through respective electronically controllable shutters, such as TFT arrays, from each of the x-, y- and z-directions. The light incident from the x- and y- directions comprises selecting energy, while the light incident from the z- direction comprises the interrogating energy, as before. Light of a colour appropriate for activation of the material in the pits such as 21 and 31 is used to write information into the volumetric data store. It is convenient
to use green light for this purpose.

If the pit 21 in layer 20 is required to be active, a beam of the one required colour (i.e. blue) from the x-direction and a beam of the other required colour (i.e. red) from the y-direction are caused to simultaneously illuminate that pit. As the two beams intersect, they create green light and thus activate that pit 21. This generates a current, as described above, and the solution in the juxtaposed reservoir pit 161 is attracted by the associated, highly localised, magnetic field. The solution then moves through the microporous coating 18 into the juxtaposed data pit 71 in layer 7. The currents generated by illumination of the pits such as 21 as described are so minute, and the associated magnetic field so small that the solution held in neighbouring reservoir and/or data pits is not disturbed sufficiently to overcome its resistance to movement through the microporous coating 18.

When the device is later read, at least one of the selecting light beams is differently coloured. Conveniently, they may be made blue and red respectively. Where they intersect at a data pit, such as 71, tinted blue by the presence of the material which it contains, this data pit will absorb all light. A white interrogating beam from the z-direction is then absorbed by this data pit and no light will reach a light sensitive pick-up device positioned as at 2 in Figures 1 - 3. By the same token, where a data pit such as 71 contains no solution, the blue and red selecting beams pass through it, as does the white interrogating beam. A signal is, in those circumstances, received and decoded as a digital '1' signal by the detector such as 2.

To empty a data pit, such as 71, of solution, thereby
enabling it to be re-written, only requires the illumination of the juxtaped pit 31 in layer 30 with green light to activate it. It will then generate sufficient electrical current and the associated electromagnetic field to pull the solution back from the data pit such as 71 into the corresponding reservoir pit such as 161.

This embodiment permits the construction of a particularly compact and mechanically simple device, as the entire range of writing, reading and rewriting can be achieved using the electronically steerable light beams which are required for the purely readable device, subject to some minor additional colouring requirements for the selecting beams.

In an alternative embodiment, as shown in fragmentary form in Figure 5, each storage level such as 3 consists of a two layer film laminate 7', 16'. Layer 7' has tiny pits, of dimensions around 10 micron cubed, etched into it to form data pits. Layer 16' has corresponding reservoirs, around the same size, etched into it. Between these layers is a coating 18' of semi-porous material, typically a coating of organic material, a few microns thick, containing millions of microscopic pores. Within the reservoir pits of layer 16' is a heat sensitive liquid with a low boiling point and low viscosity.

Layer 7' constitutes is the storage, or read area of the device and layer 16' is the write area. Electronic shutters such as TFTs are used as before to illuminate the storage device with radiation from the x- and y- directions. In this embodiment, however, there is a requirement, for each of these directions for one TFT to correspond to a data pit in the read area (layer 7') and one to the corresponding
reservoir pit in the write area (layer 16'). If data pit 71' is to be a digital '0' signal, then the TFTs in both the x- and y- axes illuminate the juxtaposed reservoir pit 161'. This causes a rise in temperature of the liquid in the reservoir pit 161', which liquid then starts to rise up, exhibiting an effect rather like osmosis. The liquid passes through the microscopic pores in the layer 18' and into the data pit 71'. Typically, the liquid is blue in colour, and it thus turns the pit 71' in layer 7 blue. This process is repeated for other pits and may be conducted in series, parallel or series/parallel configurations, depending upon the operating criteria. As the temperature stabilises after writing, the liquid has no affinity to return through the microscopic pores of the layer 18' back down to the reservoir pit 161', as it needs a rise in temperature in the data pit 71', which it now occupies, to create enough energy to return. To re-write the device, data pits in layer 7' that need to be returned to digital '1' values are illuminated. Again, the temperature rises and this forces the liquid back down to the reservoir layer 16' and thus clears the pit 71'. When reading the device, only the data storing layer such as 7' at each storage level such as 3' is interrogated through the TFTs. Layer 16' is effectively just a reservoir for the liquid and is only illuminated with light via a TFT when writing is to be effected, whereas layer 7' is addressed both in writing and in reading. The intensity and wavelength of interrogating light used when reading information from the device differs from that used when writing information into it, so that only a slight rise in temperature occurs on reading and the liquid does not have an affinity to move. In this embodiment, it is necessary to use a liquid which is not so sensitive to heat that ambient temperature variations could cause it to move from one layer
to another. It should be pointed out, however, that the device is not as sensitive to ambient temperature variations as might be expected, since both layers of a given storage level are heated or cooled simultaneously by ambient temperature variations as opposed to one layer being heated selectively during the writing process. In order for the fluid to move properly, it is advisable for the pits to be created in a vacuum so that no air needs to be displaced by the moving fluid. In addition to this, a ferrous and magnetically polarised film layer may be provided, if desired, above the pits of layer 7', whereby the fluid is provided with a further affinity for the data pit, such as 71', rather than the corresponding reservoir pit such as 161'. This remains true until the polarisation is reversed and the temperature increased in the pit area. It is therefore possible to combine illumination of the reservoir below the pit with magnetic polarisation of the ferrous coating above the pit to both push and pull the fluid into the pit and hold it there.

If the liquid is blue (for example) it will allow white light to pass through it, but will tint it blue. If the pits are interrogated from the x-direction by green light and from the y-direction by red light through a TFT array or other electronically controlled shutter, then the combination of the three colours at the intersection of a data pit such as 71' containing blue coloured fluid (a '0' signal) will cause the light to be absorbed. No signal will reach a light sensitive pick-up on the other side of the device. If the pit 71' is clear, then only the red and green lights combine, and the pick up will receive a light emission, indicating a '1' signal. The light sensitive pick up can, in this embodiment, be disposed in the x-y plane, so as to receive
light incident from the x- or y- or both directions as it is not necessary to use the z- axis for interrogating light.

To write data into the device, it is possible to expose the 5 reservoirs in layer 16' to red light from both the x- and y-directions.

In a further embodiment, which will be described with reference again to Figure 3, the various storage layers and 10 associated layers may incorporate LCD panels. Thus, for example, collimating layer 6 may consist of a film coated on its lower surface with a ferrous compound whilst storage layer 7 includes, as before, a regular array of pits into which optically active fluid may be injected or be caused to enter by magnetic forces. These magnetic forces are, in this example, generated by layer 16, which comprises a standard LCD type image generating system with an associated reservoir for the fluid. The liquid reservoirs are controlled by one on/off switch, or transistor, per each line of each axis. 20 Thus, in a two-dimensional ('single level') device, 800 transistors in the x-direction and 1,000 transistors in the y-direction can be used to open or close 800,000 data pit reservoirs. If individual data pits in level 3 are, for convenience, designated as A1, B1, A2, B2 etc and those in level 4 similarly as A1, B1, A2, B2 etc., the arrangement is such that level 3 has alphabetically designated rows of data pits (alpha-axis; or x-axis) and numerically designed columns of data pits (numeric-axis; or y-axis) - so 'Level 3, A1' defines the data pit, or pixel, located at level 3, row A, 25 column 1. The reservoir 16 contains (for example) a blue liquid crystal.

In order to write information into the volumetric data store,
a given data pit above the reservoir is filled or remains empty in dependence upon the activation or non-activation of its associated transistor. This is controlled by input data supplied as the usual 0 and 1 signals. All of the row 'A's in all of the levels are controlled by a single transistor which is always 'on'. All of the row 'B's in all of the levels are controlled by another single transistor which is always 'on', etc. The numerical transistors (i.e. those controlling each numerically designated column in each level) always start as 'off' and there is conversely a single respective transistor for each column and each level. By extending this principle to a three dimensional device, for example one with ten levels, 800 transistors are needed along the alpha-axis and 1,000 transistors along the numeric-axis on level 3. However, although, in level 4, 1,000 transistors are needed along the numeric-axis, no new ones are needed for the alpha-axis, as the transistors along the alpha-axis in level 3 are used again. The alpha-axis transistor in each row (row 'A' or row 'B' etc) is constantly switched on in all levels when information is being written into that particular alphabetic row (but only one row at a time). This means that, for example, to create a device with 8,000,000 data pits, only 800 transistors need be assigned to the alpha-axis and 1,000 multiplied by ten to the numeric-axis, i.e. 10,800 transistors for 8,000,000 bits of data. Thus, the longer the alpha-axis and the shorter the numeric-axis, the better the transistor usage figure gets. For example, having 2,000 transistors in the alpha-axis and 1,000 in the numeric-axis multiplied by ten (levels) sets up a requirement for 12,000 transistors to create a device carrying 20,000,000 bits of data. In microprocessor terminology this means that 12 kilobits of microchip enables 20 Megabytes of data. If each data pit is, say, 10 micron square by 10 micron deep,
including its wall, a device designed to carry 18 Gigabyte of data is, for example, 10,000 pits long by 6,000 pits wide; or 10 cm long and 6 cm wide. Its depth is around 3 cm, assuming 300 levels with associated LCD connectors, drivers etc., at 5 around 100 micron thick each.

In order for the data pit to remain filled or empty after it has been written, and once no further electrical current is being fed to its associated reservoir, it is necessary to ensure that the film surface above or below the reservoir remains magnetised, rather like a floppy disc. This can be achieved by means of a ferrous solution coated film which will remain polarised and therefore hold the fluid (which is susceptible to nearby magnetic fields) in magnetic suspension in the data pit.

A microporous coating is applied between the reservoir and its associated pit, in order to further aid the suspension. By later reversing the polarity of the charge from the associated transistor, the liquid crystal can be forced to move back into the reservoir and out of the data pit.

It will be appreciated that, in all embodiments, the reservoir layer (16, 16') may contain pits individually aligned with respective data pits in the data storing layer (7,7'). Alternatively, however, the reservoir may be continuous, i.e. not divided at all into pits, or there may be zonal correspondence between, for example, relatively large reservoir pits and respective groups of relatively small data pits. Furthermore, the film, layer or coating (18,18'), through which the optically active liquid must flow when passing between the data pits and the reservoir and vice versa, may be provided with special features, such as x-
and/or y-direction laminae, to resist lateral movement of the liquid and/or it may be provided with enhanced valving capabilities, enabling it to resist unwanted reversals of liquid flow.

5

A further embodiment of the present invention is based upon the principle of providing, at each data storage (pixel) location, a medium whose molecular structure can be selectively caused to adopt either a first or a second orientation mode (one of which can be general disorientation, as mentioned earlier), depending upon whether it is required to transmit or absorb interrogating light. Thus, referring to Figure 6, which shows schematically the principle of the invention, there is provided, in the lower (data storing) layer, such as 7, at each storage level, such as 3, a sealed reservoir 46 containing an optically active medium 47.

The molecular structure of the medium 47 in each individual reservoir such as 46 can be selectively orientated in dependence upon a (variable) pattern of digital information to be stored in said pits; and the molecular structure of the medium in some or all of the reservoirs such as 46 material can further be reoriented in order to permit the storage of a replacement pattern of digital information in said array.

25

The orientations are shown schematically in Figure 6 by the vertical lines in reservoir 46, indicating alignment of the molecules of the material 47 generally in the z-direction, whereas in a neighbouring reservoir 46' the molecules of the material 47' are aligned generally in the x-y plane, as indicated by the horizontal lines therein. Clearly, the orientation in any given reservoir such as 46 or 46' will depend upon the nature of the digital data value to be stored.
there, and the molecules of material in neighbouring reservoirs may be aligned in the same or different directions as appropriate to convey the stored data.

5 The orientation of the molecular structure of the medium in the reservoirs such as 46 may be achieved in various ways without departing from the scope of this invention and, in general, any procedure capable of locally controlling said orientation may be used for writing or erasure of data within the store.

In accordance with a preferred embodiment of the invention, one example of which will now be described with reference to Figure 7, the localised control of the molecular orientation of the medium 47 is achieved electromagnetically by means of photovoltaically generated electrical currents.

Referring now to Figure 7, the fragmentary portion of the storage device shown illustrates a structure intended for use at each storage level. It will be appreciated that each data storage level, or at least a sufficient plurality of those levels to ensure adequate collimation of the interrogating light incident from the z-direction, will retain the upper, z-direction collimating layer 6.

25 In the construction of Figure 7, the layer 7, the detailed construction of which will be described subsequently, is supplemented with respective vertically and laterally displaced orientation control components. These control components comprise respective uniform arrays of microscopic pits such as 51 and 61; each pit such as 51 overlying a respective reservoir such as 46, and each pit such as 61 lying closely adjacent and beside a respective reservoir such
as 46. All of the pits, such as 51 and 61, are filled with a compound, similar to the compounds used in solar cells (photo-voltaic cells), which generates a small electrical current when it is exposed to light. This compound can, for example, comprise a multi-crystalline silicone solution or a lead chalcogenide in solution, and may be tinted in one colour, for example green, so that is predisposed to filter out all other colours in the light spectrum, so reducing risk of the compound being activated by stray light. In this general connection, it can (depending upon the precise nature of the construction of the data storage device and the associated interrogating and/or selecting energy) be advantageous for the material in the pits such as 51 and 61 to be tinted in different colours, so that they respond to selecting light of different chromaticity, thereby reducing risk that the material in pit 51 (say) will be inadvertently energised by light intended to energise the closely adjacent pit 61 associated with the same, or a neighbouring, data pit 46.

When an individual pit such as 51 is exposed to light, the solution therein generates electrical current and so creates a localised electromagnetic field around that pit, sufficient to cause the molecular structure of the medium 47 in the associated reservoir 46 to adopt a first chosen orientation (say alignment in the z-direction). If the solution in a pit such as 51 is tinted green, for example, then the irradiation of that pit with green light will generate a current.

Likewise, if an individual pit such as 61 is exposed to light (possibly of a different colour) which it can absorb, then the solution therein generates an electrical current which is differently orientated with respect to the associated
reservoir such as 46 and thus creates a differently aligned magnetic field which causes the molecular structure of the medium 47 in the associated reservoir 46 to adopt a second chosen orientation (say alignment in the x-y plane).

The medium is chosen such that the first and second orientations are capable of interacting differently with interrogating light incident from the z-direction, to an extent that, in one orientation, the interrogating light is substantially unaffected by its interaction with the medium whereas, in the other orientation, the interrogating light is absorbed, or otherwise blocked or diverted, at least to an extent sufficient to provide reliably detectable differentiation between the transmission of light through the medium in its two orientations.

The pits such as 51 may be formed, as shown, in that surface of layer 6 which faces layer 7, and the pits such as 61 may be formed, again as shown, in the layer 7 itself. Alternatively, both sets of pits may be formed in layer 6, provided that the variation in molecular orientation thereby achievable provides sufficient optical differentiation for reliable data retrieval.

As a further alternative, both sets of pits such as 51 and 61 may be formed in respective thin, clear film sheets (not shown) one disposed immediately above and one immediately below the layer 7. The clear film sheets are preferably formed with molecular alignment parallel to the x- and y-axis respectively, so as to ease and control the illumination of the pits in the x-y plane.

In this example, the storage device is illuminated, as
before, through respective electronically controllable shutters, such as TFT arrays, from each of the x-, y- and z-directions. The light incident from the x- and y- directions comprises selecting energy, while the light incident from the z- direction comprises the interrogating energy, as before. Light of a colour appropriate for activation of the material in one or both of the pits such as 51 and 61 is used to write information into the volumetric data store. It is convenient to use green light for this purpose.

If the pit 51 is required to be active, a beam of the one required colour (i.e. blue) from the x- direction and a beam of the other required colour (i.e. red) from the y- direction are caused to simultaneously illuminate that pit. As the two beams intersect, they create green light and thus activate that pit 51. This generates a current, as described above, and the medium in the juxtaposed reservoir pit 46 is affected by the associated, highly localised, magnetic field so as to cause its molecular structure to adopt the first orientation. The currents generated by illumination of the pits such as 51 as described are so minute, and the associated magnetic field so small that the medium contained in neighbouring reservoir is not disturbed sufficiently to affect its molecular orientation.

When the device is later read, at least one of the selecting light beams is differently coloured. Where they intersect at a data reservoir containing material whose molecular structure is orientated in (say) the first mode, this data reservoir will absorb, or otherwise deviate, diffuse or deflect (depending upon the actual materials used and their influence upon the interrogating light employed) all light. A white interrogating beam from the z- direction is then
absorbed (or otherwise influenced) by this data reservoir such that either no light will reach a light sensitive pick-up device positioned as at 2 in Figures 1 and 2, or any light that does reach the pick-up device has a characteristic feature, such as colouration, which enables it to be ignored. By the same token, where the molecular structure of the medium in a data reservoir is disposed in its second orientation, the selecting beams pass through it, as does the white interrogating beam. A signal is, in those circumstances, received and decoded as a digital '1' signal by the detector such as 2.

To reorientate the molecular structure of the medium in a data reservoir, thereby enabling it to be re-written, only requires the illumination of the associated pit 61 with light of the appropriate chromaticity to activate it. It will then generate sufficient electrical current and the associated electromagnetic field to change the orientation of the medium’s molecular structure.

This embodiment permits the construction of a particularly compact and mechanically simple device, as the entire range of writing, reading and rewriting can be achieved using the electronically steerable light beams which are required for the purely readable device, subject to some minor additional colouring requirements for the selecting beams.

The invention can be implemented in other ways and, in an alternative embodiment, liquid crystal materials can be used at each pixel location, together with associated row and column electrode structures for effecting local molecular alignments and realignments of the liquid crystalline material, in response to the application to selected row and
column electrodes of suitable operating voltages in known manner. It is preferred to use ferroelectric liquid crystal materials in this embodiment, because they exhibit high switching speeds and well defined molecular orientations, though other liquid crystal materials, such as twisted nematics, may be used if preferred.

The liquid crystalline material may be used alone or together with other materials, and in particular may be used in conjunction with the embodiment of the invention described with reference to Figures 6 and 7 to promote or enhance molecular alignment of the material such as 47 in the pixel cavities such as 46.
CLAIMS:

1. A re-recordable volumetric data store comprising at least one storage layer formed with an array of receptor cavities corresponding to an array of storage locations, a fluid store for a fluid medium capable of exhibiting a change in at least one optical property thereof in response to a predetermined stimulant, adjacent said storage layer, septum means disposed between the fluid medium and the array of receptor cavities and urging means for encouraging the fluid medium to flow through said septum means into selected storage locations of said array in dependence upon a pattern of digital information to be stored in said array; and for encouraging said medium to return through said septum from at least some of said selected storage locations to said fluid store prior to the storage of a replacement pattern of digital information in said array.

2. A store according to claim 1 wherein said predetermined stimulant comprises magnetic forces and said urging means comprises means for generating magnetic forces locally to said cavities.

3. A store according to claim 2 wherein said urging means comprises means for generating respective magnetic forces individually for each cavity.

4. A store according to claim 2 or claim 3 wherein said urging means comprises first urging means encouraging said medium to flow in one direction through said septum and a second urging means encouraging said medium to flow in the opposite direction through said septum.
5. A store according to any preceding claim wherein said urging means comprises photovoltaic material and means for selectively illuminating respective regions of said material.

6. A store according to claim 5 wherein said photovoltaic material is provided in an array of reservoir locations disposed in one-to-one relationship with said storage locations.

7. A store according to claim 6 wherein said photovoltaic material is disposed in first and second identical arrays disposed to either side of said storage locations.

8. A store according to claim 1 wherein said urging means comprises thermal energy.

9. A store according to claim 8 wherein said medium is rendered selectively absorbent of a selected energy source capable of heating said medium.

10. A store according to claim 9 wherein said energy source comprises light in a selected wavelength band or combination of wavelength bands.

11. A store according to any preceding claim wherein said septum comprises a layer or coating of microporous material.

12. A store according to any preceding claim wherein said medium comprises liquid crystal material.

13. A re-recordable volumetric data store comprising at least one storage layer formed with an array of receptor cavities corresponding to an array of storage locations, a
fluid store for a fluid medium capable of exhibiting a change in at least one optical property thereof in response to a predetermined stimulant, adjacent said storage layer, septum means disposed between the fluid medium and the array of 5 receptor cavities and urging means for encouraging the fluid medium to flow through said septum means into selected storage locations of said array in dependence upon a pattern of digital information to be stored in said array; and for encouraging said medium to return through said septum from at least some of said selected storage locations to said fluid store prior to the storage of a replacement pattern of digital information in said array.

14. A store according to claim 13 wherein said predetermined 15 stimulant comprises magnetic forces and said urging means comprises means for generating magnetic forces locally to said cavities.

15. A store according to claim 14 wherein said urging means 20 comprises means for generating respective magnetic forces individually for each cavity.

16. A store according to claim 14 or claim 15 wherein said urging means comprises first urging means encouraging said medium to flow in one direction through said septum and a second urging means encouraging said medium to flow in the opposite direction through said septum.

17. A store according to any one of claims 13 to 16 wherein said urging means comprises photovoltaic material and means for selectively illuminating respective regions of said material.
18. A store according to claim 17 wherein said photovoltaic material is provided in an array of reservoir locations disposed in one-to-one relationship with said storage locations.

19. A store according to claim 18 wherein said photovoltaic material is disposed in first and second identical arrays disposed to either side of said storage locations.

20. A store according to claim 13 wherein said urging means comprises thermal energy.

21. A store according to claim 20 wherein said medium is rendered selectively absorbent of a selected energy source capable of heating said medium.

22. A store according to claim 21 wherein said energy source comprises light in a selected wavelength band or combination of wavelength bands.

23. A store according to any one of claims 13 to 22 wherein said septum comprises a layer or coating of microporous material.

24. A store according to any one of claims 13 to 23 wherein said medium comprises liquid crystal material.

25. A store substantially as hereinbefore described with reference to the accompanying drawings.
FIG. 2
INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER

IPC 7 G11C13/04 G11B7/24 G11C25/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 7 G11C G11B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, PAJ, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

<table>
<thead>
<tr>
<th>Category</th>
<th>Citation of document, with indication, where appropriate, of the relevant passages</th>
<th>Relevant to claim No.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>column 1, line 1 -column 3, line 33</td>
<td></td>
</tr>
<tr>
<td></td>
<td>column 2, line 6 -column 3, line 16</td>
<td></td>
</tr>
<tr>
<td></td>
<td>column 2, line 21 -column 3, line 38 figures 1-3</td>
<td></td>
</tr>
</tbody>
</table>

Further documents are listed in the continuation of box C. Patent family members are listed in annex.

* Special categories of cited documents:

*A* document defining the general state of the art which is not considered to be of particular relevance

*E* earlier document but published on or after the international filing date

*L* document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special relation (as specified)

*O* document referring to an oral disclosure, use, exhibition or other means

*P* document published prior to the international filing date but later than the priority date claimed

**T** later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

**X** document of particular relevance: the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

**Y** document of particular relevance: the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

**S** document member of the same patent family

Date of the actual completion of the international search

4 January 2001

Date of mailing of the international search report

11/01/2001

Name and mailing address of the ISA

European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016

Authorized officer

Colling, P

Form PCT/ISA/210 (second sheet) (July 1992)
<table>
<thead>
<tr>
<th>Category</th>
<th>Citation of document, with indication, where appropriate, of the relevant passages</th>
<th>Relevant to claim No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>WO 79 00096 A (PHOTOVOLTAIC CERAMIC CORP) 8 March 1979 (1979-03-08) the whole document</td>
<td>1,5-7, 13,17-19</td>
</tr>
<tr>
<td>A</td>
<td>EP 0 884 714 A (XEROX CORP) 16 December 1998 (1998-12-16) abstract figure 1</td>
<td>1,13</td>
</tr>
</tbody>
</table>

Form PCT/ISA/210 (continuation of second sheet) (July 1992)
### INTERNATIONAL SEARCH REPORT

**Information on patent family members**

<table>
<thead>
<tr>
<th>Patent document cited in search report</th>
<th>Publication date</th>
<th>Patent family member(s)</th>
<th>Publication date</th>
</tr>
</thead>
<tbody>
<tr>
<td>US 5353247 A</td>
<td>04-10-1994</td>
<td>NONE</td>
<td></td>
</tr>
<tr>
<td>US 3863249 A</td>
<td>28-01-1975</td>
<td>NONE</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>DE 69214992 D</td>
<td>12-12-1996</td>
</tr>
<tr>
<td></td>
<td></td>
<td>DE 69214992 T</td>
<td>06-03-1997</td>
</tr>
<tr>
<td></td>
<td></td>
<td>US 5359565 A</td>
<td>25-10-1994</td>
</tr>
<tr>
<td></td>
<td></td>
<td>JP 54063631 A</td>
<td>22-05-1979</td>
</tr>
</tbody>
</table>