Optical data storage medium and use of such medium

The invention relates to a multi-stack optical data storage medium for rewritable recording using a focused radiation beam entering through an entrance face of the medium during recording, comprising:

- a substrate with present on a side thereof:
- an L_0 recording stack comprising a phase-change type L_0 recording layer, said first recording stack being present at a position closest to the entrance face and having an optical transmission of T_{L0a} when the phase-change layer is in the amorphous phase, and having an optical transmission of T_{L0c} when the phase-change layer is in the crystalline phase,
- an L_1 recording stack, comprising a phase-change type L_1 recording layer, being present more remote from the entrance face than the L_0 recording stack,
- a transparent spacer layer between the recording stacks, said transparent spacer layer having a thickness substantially larger than the depth of focus of the focused laser-light beam,

the medium further comprising pre-recorded information.

The invention further relates to the use of such a medium.

An embodiment of an optical storage medium of the type mentioned in the opening paragraph is known from United States patent US 5,726,969. Rewritable optical storage for audio, video and data applications is a rapidly growing market. For Digital Versatile Disk ReWritable (DVD+RW) the storage capacity is 4.7 Gbyte. This is a limited amount of storage for video recording. With MPEG2 compression it is possible to record 1 hour of high quality digital video and 2 hours of standard quality. More recording time is desirable. An option is to use optical disks with multiple information layers (see Fig.1). Such disks are already available for DVD read only (DVD-ROM). DVD rewritable dual-recording stack disks are proposed in said known patent. The L_0 stack (i.e. the stack closest to the laser) has a transmission around 50 %. The stacks are separated by a spacer layer with a typical thickness between 30 and 60 um. The L_1 stack (stack farthest from the laser) has a high

reflection and needs to be very sensitive. The effective reflection of both stacks is typically 7% although lower and higher values are possible e.g. 3% - 18%.

The recording layers of said stacks are of the phase-change type. An optical data storage medium based on the phase-change principle is attractive, because it combines the possibilities of direct overwrite (DOW) and high storage density with easy compatibility with read-only optical data storage systems. Data storage, in this context, includes digital video-, digital audio- and software-data storage. Phase-change optical recording involves the formation of submicrometer-sized amorphous recording marks in a crystalline recording layer using a focused relatively high power radiation beam, e.g. a focused laser-light beam. During recording of information, the medium is moved with respect to the focused laser-light beam that is modulated in accordance with the information to be recorded. Marks are formed when the high power laser-light beam melts the crystalline recording layer. When the laser-light beam is switched off and/or subsequently moved relatively to the recording layer, quenching of the molten marks takes place in the recording layer, leaving an amorphous information mark in the exposed areas of the recording layer that remains crystalline in the unexposed areas. Erasure of written amorphous marks is realized by recrystallization through heating with the same laser at a lower power level, without melting the recording layer. The amorphous marks represent the data bits, which can be read, e.g. via the substrate, by a relatively low-power focused laser-light beam. Reflection differences of the amorphous marks with respect to the crystalline recording layer bring about a modulated laser-light beam which is subsequently converted by a detector into a modulated photo current in accordance with the recorded information.

An important issue for multi-stack rewritable disks is random access. When a disk is recorded for the first time the L_0 recording layer of the L_0 stack, closest to the entrance face of the laser, is partially written. Since the transmission of written and unwritten parts is different, reading and writing of the L_1 recording layer may be influenced (see Fig.2). Of special interest is the impact on the data signal, tracking and focussing signals. It is known that an optical disk drive can cope with relatively small differences in transmission e.g. fingerprints, dust, etc. When the transmission differences exceed certain values the playability of the disk is strongly degraded. In severe cases the disk will not be usable anymore. Two known solutions are possible. In the first solution the L_0 recording layer is pre-formatted or fully written before recording of the L_1 recording layer. This procedure is not desirable because it is time consuming for the user and not ideal for systems which require random access. It should be avoided if possible. The second solution is to optimize

the optical data storage medium such that the transmission difference between written and unwritten parts is very small (less than 1%). This is called balanced transmission for which at a 405 nm radiation beam wavelength good results have been reported by K Narumi (ISOM 2001). For wavelengths around 650 nm it is very difficult to achieve a balanced transmission. A disadvantage of the medium approach is that it limits the choice of phase-change materials which can be used. This can be a drawback for high-speed recording. The optical properties of materials suitable for high-speed recording at wavelengths around 650 nm are such that balanced transmission is not feasible for realistic stacks designs.

It is likely that rewritable dual-recording stack disks will be introduced in the market. Presently in the DVD forum there are discussions to use dual stack disks for high-definition TV recording. It is probable that in the near future disks with substantial transmission differences between written and unwritten parts of the L_0 layer will be used. It is a problem that substantial differences in transmission will occur in a partially written L_0 recording layer which may degrade the playability, recordability and/or random access option of the disk.

It is an object of the invention to provide an optical data storage medium of the type mentioned in the opening paragraph which has a good playability, recordability and random access behavior even when the L_0 recording layer has been partially recorded with user data.

This object is achieved with the optical data storage medium according to the invention which is characterized in that the pre-recorded information contains a flag whether pre-formatting of the L_0 recording layer of the L_0 recording stack is needed depending on the transmission values T_{L0a} and T_{L0c} of the L_0 stack.

It was found that when the optical transmissions of the user data written portion and the unwritten portion of the L_0 recording stack are within certain boundaries pre-formatting is not required. Normally, when the transmission difference between a written portion of user data and unwritten portion is too large pre-formatting, before recording user data, is the only option for leveling this transmission difference. In the latter case, without pre-formatting, e.g. the servo signals may be disturbed too much for successfully and randomly reading and recording of a further portion of the recording layers of the medium. In order to select between the option of yes/no pre-formatting, a pre-recorded dual-stack disk should contain information whether pre-formatting of the L_0 recording layer is needed or not

depending on the mentioned transmission differences. Thus pre-formatting of the L_0 recording layer before user data recording is an option, the necessity of it is pre-recorded in the medium by e.g. the manufacturer. The pre-recorded information is modulated in at least one of: an embossed pregroove in the substrate, embossed pits in the substrate and recorded phase-change marks in at least one of the recording layers L_0 and L_1. The option is added as an additional flag, e.g. one or more bits, in the pre-recorded information using e.g. available ADdress In Pregroove (ADIP) words or other pre-recording info physically present on the disk e.g. embossed pits in case another disk format is used e.g. DVD-RW. ADIP is a method of modulating data in the pregroove or guide track of an optical data storage medium. The modulation is achieved by wobbling the pregroove. The information may also be pre-recorded in the recording layer of the medium e.g. the phase-change recording layer, preferably in an area, e.g. the lead-in/lead out area or disk identification area, where it does not or hardly disturb the recording of data by the end user. The advantage of the additional flag is that it remains possible to use a wide range of materials with larger transmission differences. When applicable, the L_0 recording layer of the medium preferably is (partially) pre-formatted or recorded prior to recording of recording layer L_1.

In a preferred embodiment $0.40 < T_{L0a} < 0.60$ and $0.40 < T_{L0c} < 0.60$. When the transmissions of the written and unwritten portions of the L_0 recording stack are within these boundaries pre-formatting is not needed. In this range of transmissions the playability, recordability and random access are still acceptable. Simulations and measurements show that the transmission of crystalline and amorphous phase change stacks may vary between 40% and 60% before degradation in the tracking and other relevant signals occurs. This makes it possible to use a wide class of phase-change materials for the L_0 layer.

It is advantageous when a semi-transparent metal reflective layer is present in the L_0 stack with a thickness smaller than 15nm. At this thickness the metal still has a substantial optical transparency which is required because the focused radiation beam must also reach the L_1 layer. It is favorable when the metal mainly comprises one of Ag and Cu. These two metals have the additional advantage that they have a relatively large thermal conduction at a relatively low thickness which is favorable for the optical transmission.

In another embodiment the L_0 and L_1 stacks respectively have effective optical reflection values R_{L0} and R_{L1} which are substantially equal. This has the advantage that the modulated signals when information is read back with a focused radiation beam are well balanced. In practice R_{L0} and R_{L1} have a value between 0.03 and 0.18, typically both 0.07. The recording layers comprise at least three elements selected from the group of the elements

Ge, In, Sb and Te. Alloys of these materials have shown to be suitable for high data rates which requires high-speed recording. High-speed recording in its turn requires the phase change material to have a small complete crystallization time (CET).

In a special embodiment an additional recording stack L2 is present separated from the L_1 stack by a transparent spacer layer having a thickness larger than the depth of focus of the focused laser-light beam. In this case three recording stacks are present which enhances the data capacity with approximately another 50%.

Embodiments of the optical storage medium according to the invention and measurement results will be elucidated in greater detail with reference to the accompanying drawings, in which

Fig. 1 shows a schematic cross-sectional view of an embodiment of the optical data storage medium according to the invention including an L_0- and an L1-stack. The dimensions are not drawn to scale;

Fig. 2 shows a schematic cross-sectional view of the medium of Fig.1 in which the L_0 recording layer has been partially written;

Fig. 3 shows in more detail the stack design of the L_0 and the L_1 stack of an embodiment of the optical data storage medium according to the invention;

Fig. 4a, 4b and 4c shows the HF signal taken from an optical disk drive when reading out the LI layer when a) Lo is empty, b) L_0 is fully written, c) L_0 partially written

Fig. 5 shows eye patterns of data read from respectively L_0 and L_1 recording layers of DL disk

Fig. 6 shows the average jitter (in %) of data read from L_1 recording layer of disk with either L_0 layer written after or before L_1 writing.

Fig. 7 shows the open loop push-pull-tracking signal of the L_1 recording layer with a partially written L_0 recording layer.

Fig. 8 shows the low frequency filtered central aperture (CA) signal and 3-spots push-pull signal of an L_1 ROM layer of dual layer disk. The L_0 recording layer is partially written (half-track band).

Fig. 9 shows, inter alia, Block Error Rate (BLER) data of L_1 layer of dual layer RW/ROM disk.

Fig. 10 shows the average jitter J_{avg} (in %) and modulation M of data read from the L_1 recording layer of a dual stack disk at different track positions when L_0 layer is partially written (note that L_1 is written after partially writing L_0)

In Figs.1, 2 and 3 a schematic cross-section of a multi-stack optical data storage medium 20 for rewritable recording using a focused radiation beam 30 entering through an entrance face 25 of the medium 20 during recording is shown. The medium 20 comprises a substrate 1a, 1b with present on a side thereof an L_0 recording stack 2 comprising a phase-change type L_0 recording layer. The L_0 recording stack 2 is present at a position closest to the entrance face 25 and has an optical transmission of T_{L0a} when the phase-change layer 6 is in the amorphous phase and of T_{L0c} when the phase-change layer 6 is in the crystalline phase. An L_1 recording stack 3 with a phase-change type L_1 recording layer 11 is present more remote from the entrance face 25 than the L_0 recording stack 2. A transparent spacer layer 4 is present between the recording stacks and has a thickness of 52 μm, which is larger than the depth of focus of the focused laser-light beam 30. The transparent spacer layer 4 is made of a UV-light curable resin known in the art and may be applied by spincoating or as a sheet of transparent plastic with pressure sensitive adhesive (PSA). The medium 20 contains pre-recorded information modulated in an embossed pregroove 21 in the substrate by means of Address In Pregroove (ADIP). The modulation is achieved by wobbling the pre-groove 21, which is a known technique. The pre-recorded information contains a flag whether formatting of the L_0 recording layer 6 of the L_0 recording stack 2 is needed depending on the transmission values T_{L0a} and T_{L0c} of the L_0 stack 2.

In Fig. 2 the L_0 recording stack 2 is shown which has been partially recorded or written with data 2’ while the focused laser beam 30 focuses onto the L_1 recording stack 3.

In Fig. 3 two parts of a dual stack DVD+RW disk comprising a semi-transparent part with L_0 stack, called L_0, a spacer layer and a part with an L_1 stack, called L1, are shown. The L_0 part comprises a polycarbonate (PC) substrate 1b of 0.58 mm thickness with DVD+RW pregroove structure, not drawn in this Figure, having a groove depth of about 30 nm and ADIP info is used. The L_0 layer stack present on the substrate 1b comprises a first dielectric $(ZnS)_{80}(SiO_2)_{20}$ layer 5, a 6 nm thick phase change layer 6, which comprises at least three elements selected from the group of the elements Ge, In, Sb and Te, a second $(ZnS)_{80}(SiO_2)_{20}$ layer 7, a 3 nm Si_3N_4 capping layer 7’, a thin semi transparent metal alloy

heat-sink and reflective layer 8 of 10 nm mainly comprising Ag, a second silicon nitride capping layer 9' and a third $(ZnS)_{80}(SiO_2)_{20}$ layer 9. All layers are deposited by sputtering. The L_0 stack is a so-called IPII'MI'I stack, in which notation I represents a dielectric layer, I' a capping layer, P a phase-change recording layer and M a metal layer. On the substrate 1a of the L_1 part a thick metal reflective and heat sink layer 13 being a 50 nm Al alloy, a first $(ZnS)_{80}(SiO_2)_{20}$ layer 12, a 12 nm phase change layer 11 and a second $(ZnS)_{80}(SiO_2)_{20}$ layer 10 are deposited by sputtering. The L_1 stack is an IPIM stack, in which I, P and M have the already mentioned meaning. After initialization, i.e. crystallization, of the L_0 and the L_1 recording layers 6 and 11 the L_0 part and L_1 part are bonded together separated by a transparent spacer 4 with a thickness between 25 -60 μm, here 52 μm. The L_0 and L_1 stacks 2 and 3 respectively are designed such that they have effective optical reflection values R_{L0} and R_{L1} which are substantially equal and having a value of 7% each. The transmission T_{L0c} of the unrecorded crystalline L_0 recording stack 2 is 40%, the transmission of the recorded (amorphous) L_0 stack 2 T_{L0a} is 52%. The effective transmission of a recorded part is close to 43 %, i.e. ¼ of area is mark. Thus for the transmission of the written area of the L_0 stack 2 a transmission equal to $(3T_{L0c}+T_{L0a})/4$ was assumed. An additional recording stack L2, not shown, may be present separated from the L_1 stack by a transparent spacer layer having a thickness substantially larger than the depth of focus of the focused laser-light beam. In this case the transmission levels of the L_0 and L_1 stacks have to be adjusted in order to balance effective reflection values form the L_0, L_1 and L2 stacks.

In Fig. 4 the HF read out signal of the L_1 recording layer 6 from a dual stack disk is shown for three cases. In 4a the trace with L_0 unwritten is shown, in 4b with L_0 written and in 4c for a partially written L_0 layer, i.e. bands of 70 pregroove tracks written/unwritten. Clearly in the HF signal some effect of the written tracks in the L_0 layer can be seen. Recording results in the form of eye patterns are shown in Fig. 5 for the L_0 and L_1 recording layers.

In Fig.6 Direct Overwrite (10 DOW cycles) average jitter J_{avg} is around 11% for the L_1 recording layer 6, which is represented by graphs 61 to 64. J_{avg} levels of the L_1 recording layer 11 of below 9 % may also be achieved, which is shown in Fig. 10. Jitter of the L_0 recording layer is around 9%. The average jitter value of the L_1 recording layer 2 is slightly affected by the status of L_0 recording layer 2. Two experiments are shown. In the first experiment the L_1 recording layer is written first and afterwards L_0, in this way the read effects are studied because L_1 writing is always the same independently from the L_0 pattern. Graph 61 represents a linear fit of jitter data before L_0 is written and 62 after L_0 is written. In

the second experiment L_0 is written first and afterwards L1, in this way both the influence of a partially written L_0 disk on the writing and the reading is simulated. Graph 63 represents a linear fit of jitter data before L_0 is written and 64 after L_0 is written. The latter method (L_0 first) is also used in Fig.10.

Fig. 7 shows the open loop push-pull-tracking signal of the L_1 recording layer with partially written L_0 recording layer. The open loop signal is the tracking signal when the laser is not tracking on a pregroove, i.e. the tracking servo is not activated. No substantial disturbance is visible in the signal.

In Fig. 8 it is shown that normalized push pull and central aperture (CA) signals 82 and 81 were not severely degraded. In order to test the influence of a partially written L_0 recording layer on the bit error rate data rate of the L_1 layer a dual layer disk with a read only ROM L_1 layer was fabricated. The ROM disk data consisted of a video stream (ECC correct data). The reflection of the ROM disk was comparable with that of the previous L_1 layer. As a test pattern a band of half-tracks was written in L_0, in which case only a 180-degree portion of the full rotation of several adjacent tracks is recorded. This is considered as the worst case pattern for bit errors. The 3-spot push pull signal 82 of the ROM layer is shown where the focused laser beam crosses an L_0 written/unwritten transition. The normalized signal is affected slightly, but no substantial offset can be observed. Tracking is without problem but note that the push-pull signal 82 is small because of the use of the ROM disk as L_1 disk. The block error rate (BLER) was low, all blocks could be corrected and no effect of the partially written L_0 recording layer is observed even for this worst case situation, which is shown in Fig. 9 in curve 91. Other measured parameters in Fig.9 are not considered relevant at this time.

The impact of a partially written L_0 recording layer 6 was investigated by modeling of the push-pull signal. The calculation results are shown in Table 1 as a function of the transmission T_{L0a} and T_{L0c}. The position of the focused laser beam 30 is such that half of the beam passes a written area. For the transmission of the written area a transmission equal to $(3T_c+T_a)/4$ was again assumed. Clearly for $0.40 < T_{L0a} < 0.60$ and $0.40 < T_{L0c} < 0.60$ the offset in the push pull signal is small (< 2 nm) and significantly smaller than the allowed 16 nm which is the maximum allowed value according to the DVR+RW format specification book version 1.1.

Hence both experimental results and simulations show that for a realistic range of transmission values T_{L0a} and T_{L0c} of 0.40 to 0.60 the influence of writing information in the L_0 recording layer 6 on the tracking and read-out system is substantially absent.

T_{L0c}	0.4	0.5	0.6
T_{L0a}			
0.4	0.0 nm	0.78 nm	1.33 nm
0.5	-0.93 nm	0.0 nm	0.65 nm
0.6	-1.8 nm	-0.75 nm	0.0 nm

Table 1: Calculated push-pull offset (in nm) for variable transmission differences of written and empty tracks. The position of the focused laser beam is such that half of the beam 30 passes a written area.

In Fig. 10 the influence of a non-written or written L_0 recording layer 6, when the L_1 recording layer 11 is written through the partially written L_0 recording layer 6, on the average jitter J_{avg} of an L_1 recording layer of DVD+RW Dual Stack disk is shown. At positions where the L_0 recording layer has been written the J_{avg} decreases about 0.5 %. Variation in J_{avg} along the disk is about 0.5%. The pattern written in the L0 recording layer consisted of 5 times 100 tracks EFM+ alternated with 100 empty (non-written) tracks, 500 tracks L_0 EFM data (a half-circular pattern is written as described with Fig. 8), 100 empty tracks and 1000 tracks of EFM+ L_0. This pattern is clearly visible in the modulation (M) curve 102. In areas where the L_0 recording layer is written the J_{avg} decreases because the transmission of the L_0 stack is about higher, i.e. about 10 % relatively. This causes an increased laser recording power in the L_1 recording layer which in its turn causes the modulation to increase and the J_{avg} to drop, which is clearly visible in curve 101.

It should be noted that the above-mentioned embodiments and experimental data illustrate rather than limit the invention, and that those skilled in the art will be able to design many alternative embodiments without departing from the scope of the appended claims. In the claims, any reference signs placed between parentheses shall not be construed as limiting the claim. The word "comprising" does not exclude the presence of elements or steps other than those listed in a claim. The word "a" or "an" preceding an element does not exclude the presence of a plurality of such elements. The mere fact that certain measures are recited in mutually different dependent claims does not indicate that a combination of these measures cannot be used to advantage.

According to the invention, a multi-stack optical data storage medium for rewritable recording using a focused radiation beam, entering through an entrance face is described. The medium has a substrate and an L_0 recording stack and an L_1 recording stack

both comprising a phase-change type L_0 and L_1 recording layer and the recording stacks are separated by a transparent spacer layer. The L_0 recording stack is present at a position closest to the entrance face and has an optical transmission of T_{L0a} and T_{L0c} when the phase-change layer respectively is in the amorphous phase and in the crystalline phase. The medium contains pre-recorded information modulated in at least one of: an embossed pregroove in the substrate, embossed pits in the substrate and recorded phase-change marks in at least one of the recording layers L_0 and L_1. The pre-recorded information contains a flag whether formatting of the L_0 recording layer of the L_0 recording stack is needed depending on the transmission values T_{L0a} and T_{L0c} of the L_0 recording stack. In this way it is achieved that the medium has a good playability, recordability and random access behavior even when the L_0 recording layer has been partially recorded with information.

CLAIMS:

1. A multi-stack optical data storage medium for rewritable recording using a focused radiation beam entering through an entrance face of the medium during recording, comprising:

- a substrate with present on a side thereof:
- an L_0 recording stack comprising a phase-change type L_0 recording layer, said first recording stack being present at a position closest to the entrance face and having an optical transmission of T_{L0a} when the phase-change layer is in the amorphous phase, and having an optical transmission of T_{L0c} when the phase-change layer is in the crystalline phase,
- an L_1 recording stack, comprising a phase-change type L_1 recording layer, being present more remote from the entrance face than the L_0 recording stack,
- a transparent spacer layer between the recording stacks, said transparent spacer layer having a thickness substantially larger than the depth of focus of the focused laser-light beam,

the medium further comprising pre-recorded information, characterized in that the pre-recorded information contains a flag whether formatting of the L_0 recording layer of the L_0 recording stack is needed depending on the transmission values T_{L0a} and T_{L0c} of the L_0 stack.

2. An optical data storage medium as claimed in Claim 1, wherein the pre-recorded information is modulated in at least one of: an embossed pregroove in the substrate, embossed pits in the substrate and recorded phase-change marks in at least one of the recording layers L_0 and L_1.

3. An optical data storage medium as claimed in Claim 1 or 2, wherein $0.40 < T_{L0a} < 0.60$ and $0.40 < T_{L0c} < 0.60$.

4. An optical data storage medium as claimed in any one of Claims 1 - 3, wherein a semi-transparent metal reflective layer is present in the L_0 stack with a thickness smaller than 15nm.

5. An optical data storage medium as claimed in Claim 4, wherein the metal mainly comprises one of the elements Ag and Cu.

6. An optical data storage medium as claimed in any one of Claims 1 - 5, wherein the L_0 and L_1 stacks respectively have effective optical reflection values R_{L0} and R_{L1} which are substantially equal.

7. An optical data storage medium as claimed in Claim 6, wherein R_{L0} and R_{L1} have a value between 0.03 and 0.18.

8. An optical data storage medium as claimed in Claim 1, wherein the recording layers comprise at least three elements selected from the group of the elements Ge, In, Sb and Te.

9. An optical data storage medium as claimed in any one of the preceding Claims, wherein an additional recording stack L2 is present separated from the L_1 stack by a transparent spacer layer having a thickness larger than the depth of focus of the focused laser-light beam.

10. Use of an optical data storage medium according to any one of Claims 1-9 for multi-stack and random access rewritable data recording.