Blue Laser Optical Recording

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Abstract

The use of a blue diode laser (405 nm wavelength) provides an increase in storage density by a factor of about 2.5 with respect to DVD which uses a red laser. Another factor of two is made possible by increasing the numerical aperture of the objective to 0.85 (DVD has 0.60). We have developed all basic technologies for such a system, that is able to record 22.5 GB on a single sided 12 cm diameter disc, at a user data rate of up to 50 Mb/s.

Physical Concept

A diffraction limited focused laser beam has a focal spot diameter scaling as λ / NA, where NA is the objective lens numerical aperture given by $NA = n \sin\theta$ with n the refractive index (1 in air) and θ the opening angle of the lens. In going from CD to DVD, the seven-fold increase in capacity was mainly enabled by reducing the spot size

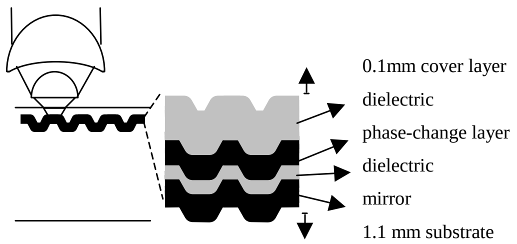

Figure 1: *Physical concept of the DVR system.*

by using shorter wavelength light (650 nm instead of 780 nm), and by increasing the numerical aperture of the objective (NA=0.6 instead of 0.45). In addition, manufacturing tolerances of the discs and the drives had to be tightened, changes were made to the data format and the channel modulation code, and a more powerful error correction scheme was introduced. Finally, to keep operating margins for parameters such as disc tilt and focus error within acceptable levels, the substrate thickness had to be halved to 0.6 mm. But to maintain mechanical stability and the same physical appearance as a compact disc, a DVD consists of two 0.6 mm substrates bonded back-to-back.

To realize a capacity of up to 22.5 GB (5 times that of DVD), the DVR system is based on a a blue diode laser [1], and an NA=0.85 objective lens [2]. The high numerical aperture places stringent constraints on disc tilt (due to comatic aberration) and on variations in disc thickness (due to spherical aberration), and it results in a shorter depth of focus.

Backwards compatibility with DVD favours an approach where the substrate thickness is kept at 0.6 mm, as in DVD. One then has to apply active tilt correction, by mounting the objective lens in an actuator with 5 degrees of freedom that need to be controlled dynamically [3]. Since this would be difficult to manufacture, we use another solution, first proposed by Sony [2], and illustrated in Figure 1. The information layer is addressed through a 100 micron thick transparent plastic cover layer, rather than through the substrate. Its thickness has been fixed at 100 micron. For this choice of cover layer thickness, a disc tilt of 0.3° in the radial direction and 0.15° in the tangential direction is allowed (comparable to DVD specifications).

A two-element objective lens is required to achieve the high numerical aperture (see Fig. 1). By changing the distance between the two lenses – using a simple actuator- it is possible to compensate for spherical aberration induced by cover layer thickness variations [3]. For mass manufacturing, we prefer a rigid two-element lens instead. This is possible by specifying a maximum deviation of the cover layer thickness of ± 3 μm from the nominal thickness. One good candidate for cover layer processing is spin-coating of a resin. An alternative method is to glue a 100 μm thick poly carbonate sheet on the carrier substrate by a UV-curable bonder or by pressure sensitive adhesive.

Two-Element Objective

In designing an NA= 0.85 lens, one aim is to provide enough space between the lens and the disc to prevent collisions. This requires a two-element lens constructed out of two aspherical lenses. We succeeded in making a two-lens objective with a NA of 0.85 for 405 nm, a pupil diamter of 3 mm, and a free working distance of 0.15 mm using the standard glass-photo polymer replication process [4]. The tolerance for tilt alignment between the two lenses is 0.7 mrad (resulting in 15 mλ wavefront aberrations, primarily coma), while the decentering alignment should be within 14 mλ. As these tolerances for alignment are small, special attention has been given to the design of the rigid lens mount, and to an accurate assembly procedure.

Figure 2: *rigid two-element objective lens.*

Phase Change Recording

Also shown in Fig. 1 is the phase change stack, used to write and erase data. This stack is similar to that in a CD-RW disc, but is deposited in reverse order. A significant effort has been spent to develop media for the blue laser/high NA optics, and to increase the data rate [5-7]. The key difficulty is that the attainable density in a phase change disc is limited by thermal phenomena such as cross erase. It is not evident that these undesired phenomena would scale with the optical spot size. Also, we wanted to achieve a high data rate, to allow multiple stream recording, and editing of HDTV content.

We found that scaling of the attainable density and also of the data rate is possible in fast growth materials (FGM). CD-RW and DVD+RW use FGM's for its phase-change material (typical composition AgInSbTe), whereas DVD-RAM employs nucleation determined materials ($Ge_2Sb_2Te_5$ type). In FGM media the amorphous mark shrinks from its edges when the temperature rises. The smaller the marks, the shorter the crystallisation time and therefore the faster the media. In nucleation determined materials, on the other hand, the crystallization time is not dependent on the amorphous mark size, and no strong dependency between data density and data-rate is expected. The correlation between spot size and achievable data-rates is illustrated in Fig. 3 for the two types of material. By further optimization of the materials and write strategies, we expect that data-rates of 70-80 Mbit/s are achievable.

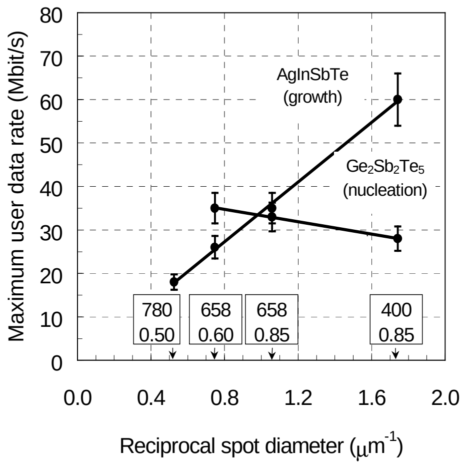

Figure 4: *Scaling of the maximum user data rate with reciprocal spot diameter for the FGM type materials (e.g. AgInSbTe) and for nucleation determined materials (e.g.* $Ge_2Sb_2Te_5$*).*

Physical Format and Drive Implementation

The physical layer format for DVR, developed jointly with Sony, is described in detail in [8]. A new channel modulation code has been constructed, 17PP, being an abbreviation of (1,7)RLL Parity Preserve Prohibit Repeated Minimum Transition Runlength. This d = 1 code offers a good recording performance, and it allows a higher write data rate than d = 2 codes. The use of a 0.1 mm thin cover layer through which the phase change layer is addressed makes the system more sensitive to dust and scratches on the optical disc, as compared to CD and DVD. For this reason a new error correcting code (64 kB LDC + BIS Picket code) has been developed, making DVR a robust and reliable storage system.

In our laboratory, a DVR bit-engine has been built, capable of recording and playback of HDTV video streams [9]. The bit-engine comprises a fully functional optical disc system, where optics, mechanics and part of the electronics are miniaturised, yielding a small, standard form factor optical drive. In Figure 10 all ingredients of the DVR drive are depicted schematically. Apart from the pre-amplifier all servo and channel electronics is implemented in a digital fashion, using field programmable gate arrays. The user data rate is limited to 35 Mb/s by the speed of the current FPGA'S. A next step to increase the maximum data rate will be the realisation of dedicated channel and servo IC's for DVR. A user data rate of more than 50 Mb/s will become feasible then.

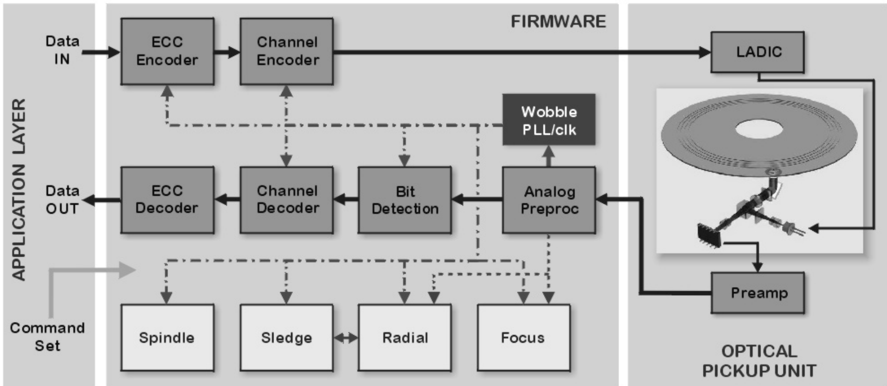

Figure 4. *DVR drive system overview.*

In conclusion, we have defined a third generation optical recording system based on a blue diode laser and a high NA lens, and we have shown its proper functioning using a prototype drive.

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