Key Technology for Ultra Density Optical

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ABSTRACT

Ultra Density Optical (UDO) has been designed as the Phase Change successor to 5¼-inch Magneto Optic data storage products, with a UDO road map spanning three product generations leading to 120GB capacity. First generation UDO will utilise 405nm wavelength, 0.7NA drive optics with 100 micron cover layer media construction in a robust, double-sided cartridged format with 30GB capacity. There will be two types of UDO, both aimed at the professional market: UDO Write Once for high density, high data rate, archival data storage applications, and high cyclability UDO Rewritable. The features of UDO and the underlying Media Engineering optimisation strategies are discussed.

INTRODUCTION TO ULTRA DENSITY OPTICAL

Since the 1980's, the market for professional archival data storage applications (such as banking, the insurance industry and government) has been addressed by a range of optical data storage technologies, especially magneto optic (MO) media in a 5¼-inch form factor. The capacity of these discs has typically doubled approximately every two years. However, the technical requirements to increase the capacity have become increasingly difficult for MO: a witness to this is the fact that the most recent MO capacity increase has been from 8x to 14x rather than the 16x one might expect.

By contrast, the development of new phase change technologies such as Blu-ray disc demonstrates the ability of phase change to meet the growing capacity and speed requirements during this decade. Whilst Blu-ray addresses the needs of the consumer market, Ultra Density Optical (UDO) has been developed as a permanent, professional, and cost effective product for the enterprise archival data storage market. The key features of UDO, with a roadmap extending at least three generations: 30GB, 60GB and 120GB, are summarized in ***Table 1***.

UDO ULTRA DENSITY OPTICAL	**UDO Generation 1**	**UDO Generation 2**	**UDO Generation 3**
Capacity	30GB	60GB	120GB
Transfer Rate	Up to 8 MB/s	Up to 12 MB/s	Up to 18 MB/s
RPM	2000 rpm	3000 rpm	3600 rpm
Avg Seek Time	25 msec	25 msec	25 msec
Numerical Aperture	0.7	0.7	0.85
Media Layers	1	2	2
Encoding	1,7 RLL	1,7 RLL	ML
Sector Size	8 kB	8 kB	8 kB
SCSI Transfer Rate	80 MB/s	80 MB/s	80 MB/s
Load Time	5 seconds	5 seconds	5 seconds
Unload Time	3 seconds	3 seconds	3 seconds
MSBF (Mean Swaps between Failures)	750,000	750,000	750,000

Table 1: UDO Specifications

UDO FEATURES

The core technology for UDO is essentially similar to Blu-ray although there are a number of key differences. The main features of UDO are:

- UDO is based on blue laser recording using λ=405nm lasers from Nichia.
- The numerical aperture (NA) for the first two UDO generations will be 0.7. This design choice was made because it was considered that the technology for 0.85NA lenses would not be sufficiently mature to enable a product to be brought to market in 2003. The 0.7NA Opto-Mechanical Assembly (OMA) is from Pentax.
- The high NA optics requires the use of 100μm cover layer construction.
- The UDO drive is multifunctional, with both true Write Once and Rewritable phase change media.
- UDO form factor is 5¼ inch, double sided and cartridged. The product is designed to have the same drive and cartridge overall dimensions ("form factor") as that used for 5¼" MO, which will enable UDO drives and media to continue to be used in libraries based on handling this size of disc (***Figure 1***).
- The read channel uses enhanced SISIC[1] (selective inter symbol interference cancellation).
- UDO is a land and groove recording format.
- UDO discs are zoned constant angular velocity (ZCAV): each disc is divided into 16 recordable zones.
- UDO has preformatted headers and wobble addressing. Embossed Quadrature Wobble Marks are incorporated in the headers – these patterns provide a method of radial tracking offset control for both groove and land recording data tracks.
- The laser driver incorporates a novel method of laser noise suppression (patent pending).

Figure 1: UDO Drive and Cartridge

DESIGN FOR ROBUSTNESS

UDO media is cartridged because it is aimed primarily at data storage applications and will frequently be used in libraries. For long life in such conditions, a rugged cartridge is required. Contamination increasingly becomes an issue in high-density media such as UDO. Not only are the mark sizes very small, but the fact that the media is read through a thin, 100μm cover layer reduces the tolerance to dust. To address this, the overall UDO product design incorporates many special features to increase robustness against dust contamination. One of the main features is the cartridge design, which uses a dual sided shutter door: we have found from our extensive dust studies that the top side of conventional discs collect many times as much dust as the bottom side. Unlike MO media, where the shutter doors on both the A and B sides need to open in order to allow access for MO coils, for phase change UDO it is only necessary to open the cartridge shutter on the underside of the disc (from which writing and reading takes place). ***Table 2*** summarises the benefits of the dual-shutter design:

0.5 hour Dust Chamber Trials	Conventional 14x MO cartridge and drive	UDO drive and dual-shutter cartridge	UDO dust reduction ratio compared with MO
Total dust particles top side	12,505	541	23.1
Total particles lower side	689	91	7.6
Average particles/side	6,597	316	20.9

Table 2: Effect of UDO drive and cartridge design to reduce dust build up

Other UDO features to increase robustness against dust include engineering the cartridge geometry to reduce dust ingress, control the air flow, and prevent the generation of dust due to wear within the cartridge itself. The cartridge material is a special, new anti-static polycarbonate. Plasmon's UDO libraries and stand-alone drives feature filtration in the cooling air channels. The media itself is hard-coated so that, if necessary, it can be cleaned. The format of the media has been designed for robustness, including:

- sectored format with backup VFO within the data field
- 8k sector size with ECC interleave of 38 codewords (Reed-Solomon code)
- the read channel identifies burst-erasures for the ECC from reference fields.
- the header format contains three address fields for each sector

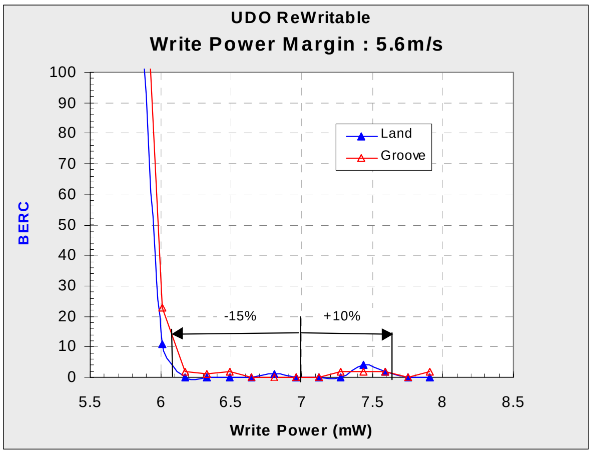
Thus although the higher densities and thin cover layer construction of UDO make it more susceptible to dust, the incorporation of all the features described mean that UDO will be highly resilient to dust with performance surpassing that of 14x MO.

UDO PHASE CHANGE MEDIA DESIGN CRITERIA

The primary market for UDO will be write once applications. In order to fulfil the increasing number of legislative requirements to provide an unalterable audit trail, the need for true write once media is becoming more and more important. Unlike MO media which is inherently rewritable (with write once functionality being achieved through software), phase change coatings can be designed to be truly write once. However, because some applications require rewritability, the UDO drives are multifunctional, and both UDO write once and UDO rewritable media have been developed. The two types of media have slightly different formats (minor differences in the formatted information and groove geometry) but very different phase change alloy coatings, each optimised according to their application: archival true write once or high cyclability rewritable. In the following sections, I shall discuss some of the design considerations leading to the selection of the phase change materials and stack development for each type of UDO media and illustrate the resulting performance.

UDO REWRITABLE MEDIA

UDO rewritable is based on fast growth phase change, the active layer being an Sb-Te-Ge alloy close to the $Sb_{69}Te_{31}$ eutectic composition. UDO rewritable is a high density, fast recording media combined with high cyclability, and high resistance to cross erase. ***Figures 2-4*** show typical results for the UDO power margin, overwrite performance and cross erase, with in excess of 20,000 direct overwrite cycles being achieved. Note that BERC is a measure of byte error rate, with results less than 30 being acceptable to the drive.



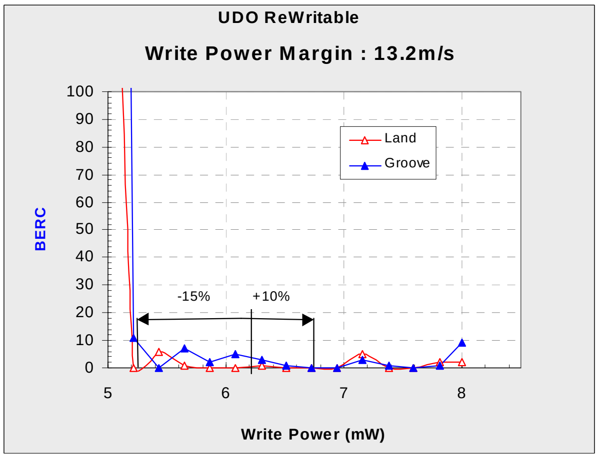


Figure 2: UDO Rewritable Write Power Margin plots of BERC (a measure of BER within a sector, results below 30 are acceptable to the drive) as a function of write power, for land and groove recording at inner and outer diameter velocity

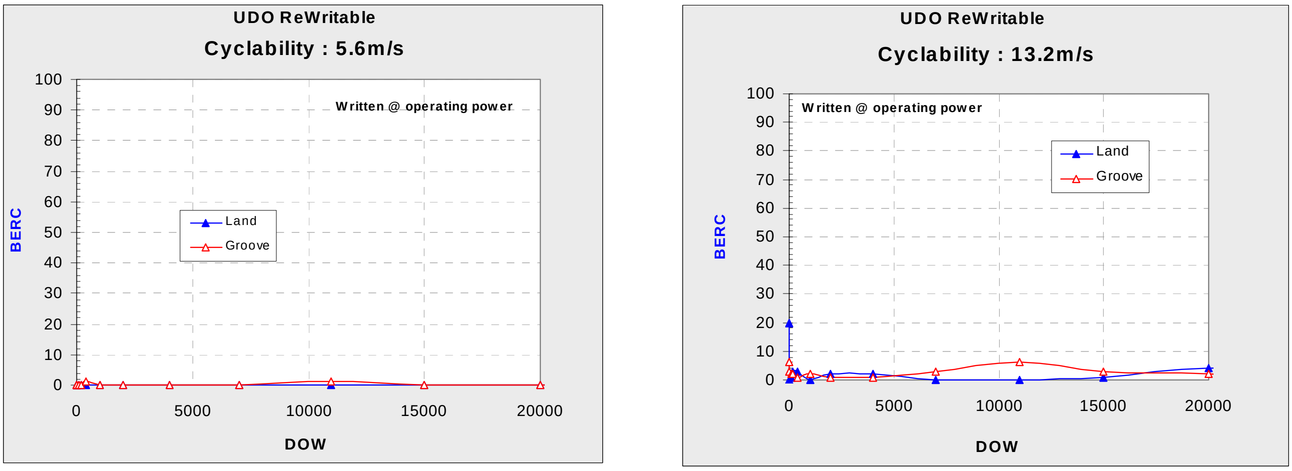


Figure 3. UDO Rewritable Cyclability: BERC plotted as a function of number of direct overwrite cycles for land and groove recording at the inner and outer diameter recording velocity

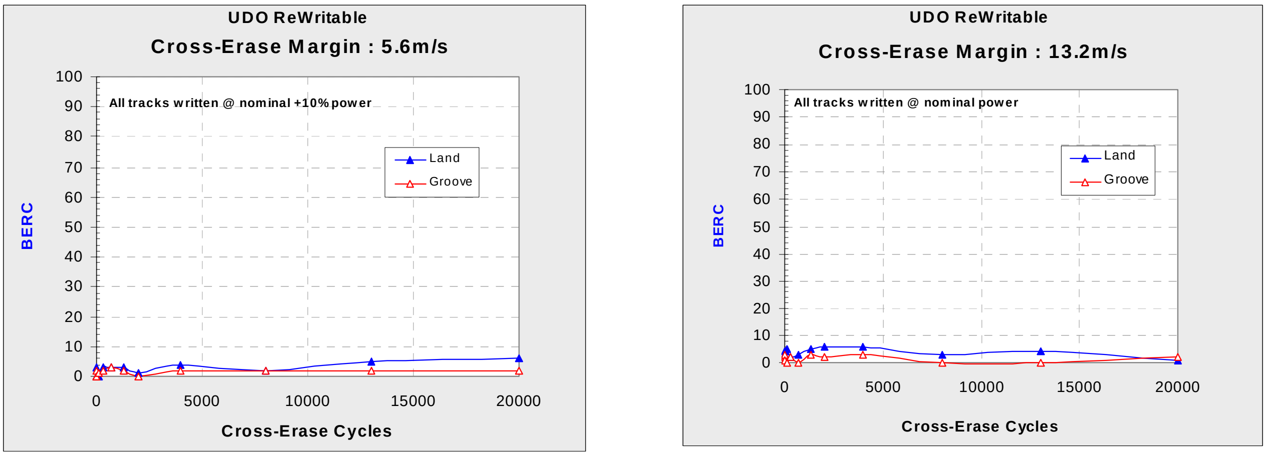


Figure 4. UDO Rewritable Cross Erase Margin plots of BERC as a function of number of cross erase cycles (repeated overwrites in the adjacent tracks) for land and groove recording

UDO WRITE ONCE MEDIA

The development of write once media presents significant and different challenges from those posed for rewritable media. The key challenge is to achieve the same density and recording rates as rewritable in a write once material. This requires reliable formation of small, stable marks with high optical contrast in a material which, by its very nature, has to be nucleation dominated.

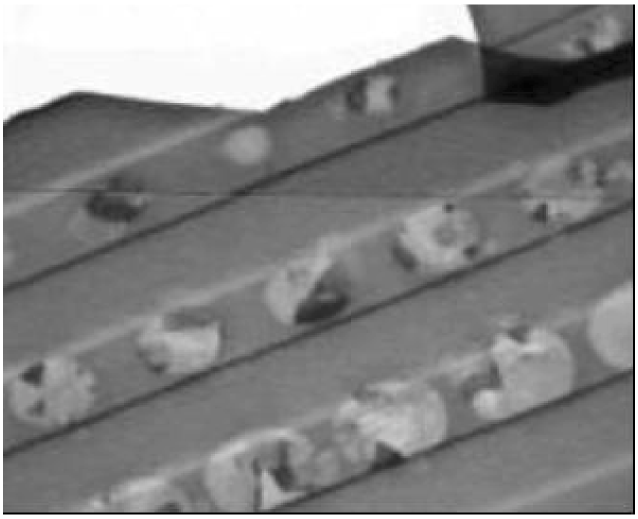
For UDO, we have selected a new phase change system that has been developed by the Eastman Kodak Company[2] with a cermet active layer encapsulated in a simple four-layer stack. This material has exceptional performance in the key areas identified as challenges for write once: high nucleation density, high contrast, bright-to-dark recording mechanism and excellent environmental stability leading to long archival lifetime. These aspects will be described in more detail in the following sections and recording results for UDO write once presented.

RECORDING DENSITY
Whilst the recording mechanisms and issues for rewritable media have been widely discussed in the literature in recent years[3,4,5,6,7,8,9], relatively little has been discussed about the mechanisms of write once phase change recording. TEM (transmission electron microscopy) is a useful tool for illustrating what is happening (***Figure 5***).

A typical mark from a *rewritable* fast growth material phase change stack is shown in ***Figure 5(a).*** We see that the mark itself is amorphous and that the initialised regions around the mark are crystalline – whereas for a write once disc, the reverse is the case. The shape of the rewritable mark is very different from the write once mark media. For a fast growth rewritable material, the recording mechanism is the formation of an amorphous mark within a crystalline matrix, whilst the erase/overwrite mechanisms is crystal growth from the mark edges.

Figure 5: Transmission Electron Microscopy photographs to compare marks in Rewritable and Write Once phase change media.

Fig 5(a) – Right - Amorphous mark recorded in crystalline matrix of a fast growth rewritable alloy



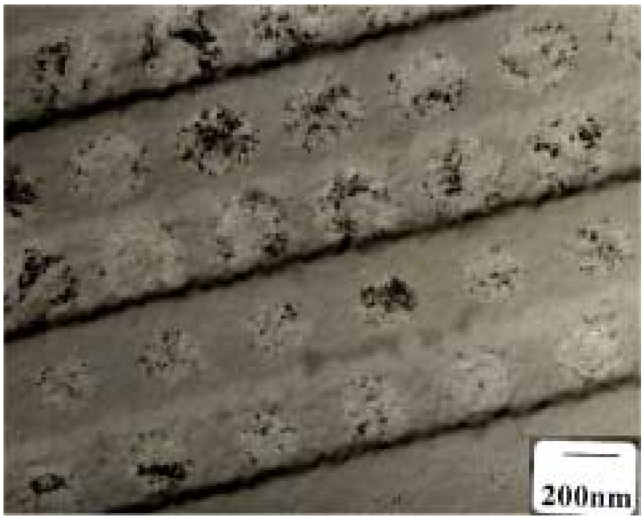


Figure 5(b) Write Once Material used for 12-inch media. The marks at the top are written at low power, those at the bottom at high power.

Figure 5(c) UDO Write Once Material The marks at the top are written at high power, those at the bottom at low power

By contrast, the TEM images of marks in write once media are quite different. ***Figures 5(b)*** and ***5(c)*** show two different write once materials, written with 2T marks. In both cases, we see that the marks are very different from the rewritable case. First of all, the write once marks are crystalline within an amorphous matrix. Writing requires nucleation and growth of small crystalline marks – a nucleation dominated mechanism. A second difference between write once and rewritable is the shape of the marks: the 2T marks for the write once material are well defined, near circular marks, which increase in dimension as the write power increases. The periphery of each mark corresponds to an isotherm associated with the energy from the write laser pulse. Once nucleated, the crystal growth process is very rapid and only slows down once it reaches the cooler part of the temperature profile.

As the capacity of optical media increases, the mark size has to become smaller and smaller. Whilst this is an advantage for fast growth rewritable materials, it can be a problem for write once media because the volume of material which is heated up and in which nucleation needs to take place reduces, increasing the difficulty of mark formation. This is illustrated in ***Figure 5(b)*** which shows the first write once material we considered for UDO**.** The regions of different contrast denote different grains, each growing from a nucleus. Whilst the higher power marks developed from approximately 8-10 nuclei, the smaller marks formed at lower powers only have one or two nuclei. This led to our reconsidering the choice of phase change material and the selection of a new cermet material[2] for the UDO write once system. ***Figure 5(c)*** shows that alloying the phase change material with the dielectric material has increased the nucleation density, especially for the smaller marks. This results in highly reliable mark formation and enables high density, high data rate recording for UDO write once.

CONTRAST

A further design criterion for UDO write once media was that it should "write dark", with the crystalline marks appearing dark against a bright background – similar to UDO Rewritable. This simplifies the drive design. However, in many types of phase change write once media based on simple stacks with a single layer (the active layer) the written crystalline marks are bright against a dark amorphous background. This would have several negative consequences for the drive design. The first is that the resultant reflectivities would be quite different for write once and rewritable media types.

The second is that modelling has also shown that signal amplitudes on land and groove tracks are different if there is a phase difference $\Delta\phi_{ca}$ between light reflected from amorphous and crystalline states. ***Figure 6*** shows how the ratio of signals on land and groove (S_{land}/S_{groove}) varies as a function of $\Delta\phi_{ca}$ and R_w/R_u (the ratio of the written and unwritten reflectivities respectively). In the case of bright-dark recording ($R_w/R_u<1$) S_{land}/S_{groove} is less sensitive to $\Delta\phi_{ca}$ than in the case of dark-to-bright recording ($R_w/R_u>1$). Hence, even if the stack cannot be designed to give zero $\Delta\phi_{ca}$, the land and groove signals should be close for bright-to-dark recording.

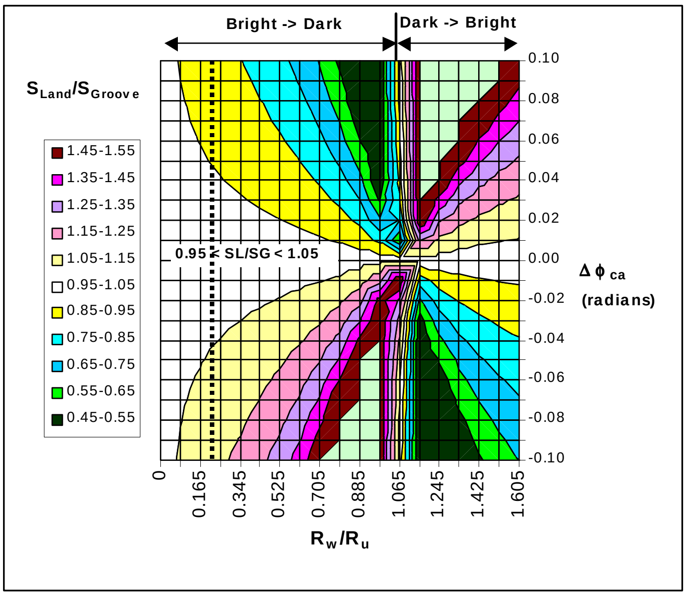


Figure 6: Modelled results demonstrate how phase effects influence the ratio of signals between land and groove

The use of the new phase change system with a four-layer bright-to-dark recording mechanism adopted for UDO write once has overcome these potential problems. Because the new phase change system has a much lower optical absorption than many other phase change alloys, it is well suited to incorporation in a multi-layered stack. This property has the further advantage that it can be adapted for dual layer recording, which is being developed for second generation UDO.

LIFETIME

For archival data storage media, a proven lifetime in excess of thirty years is essential. Arrhenius tests at elevated temperature and humidity for UDO are under way. Prior to these, we have carried out extensive screening tests under harsh conditions (80°C/85%RH) to identify potential corrosion mechanisms, originating either within the stack or resulting from incompatibility problems with the novel cover layer construction required for high NA recording. To date, no corrosion has been seen for UDO write once.

WRITE ONCE PERFORMANCE

The new phase change system used for UDO satisfies our design requirements for high density, high speed recording combined with long lifetime and bright to dark recording mechanism, with high performance margins. ***Figure 7*** shows the wide power margin for land and groove recording. ***Figure 8*** confirms the read stability of UDO write once media at powers well in excess of the nominal read power.

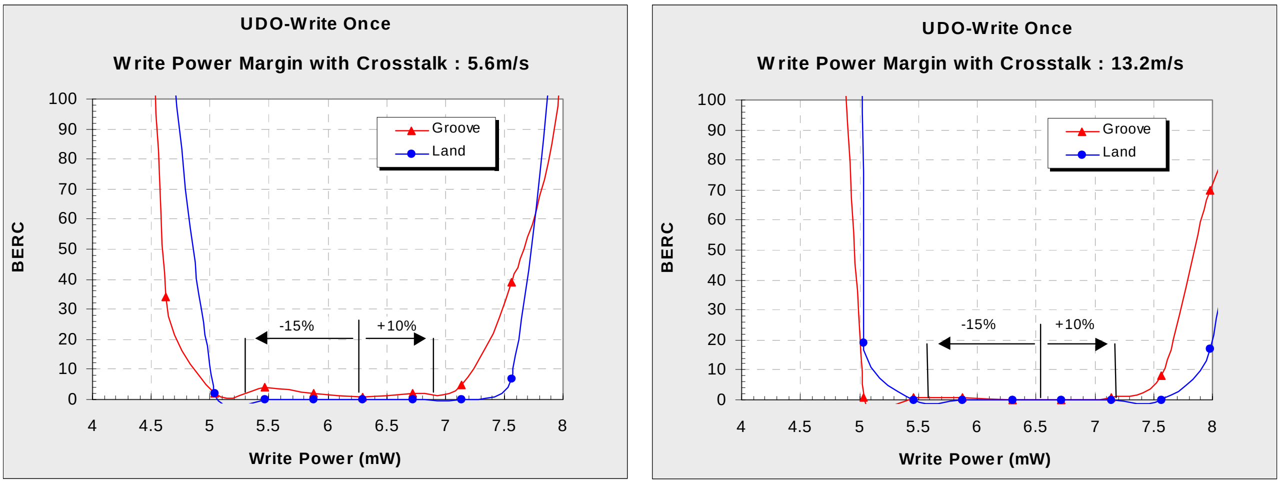


Figure 7: Power Margin plots of Byte Error Rate (BERC is a measure of BER within a sector, results below 30 are acceptable to the drive) as a function of write power for writing at the inner and outer diameter recording velocity

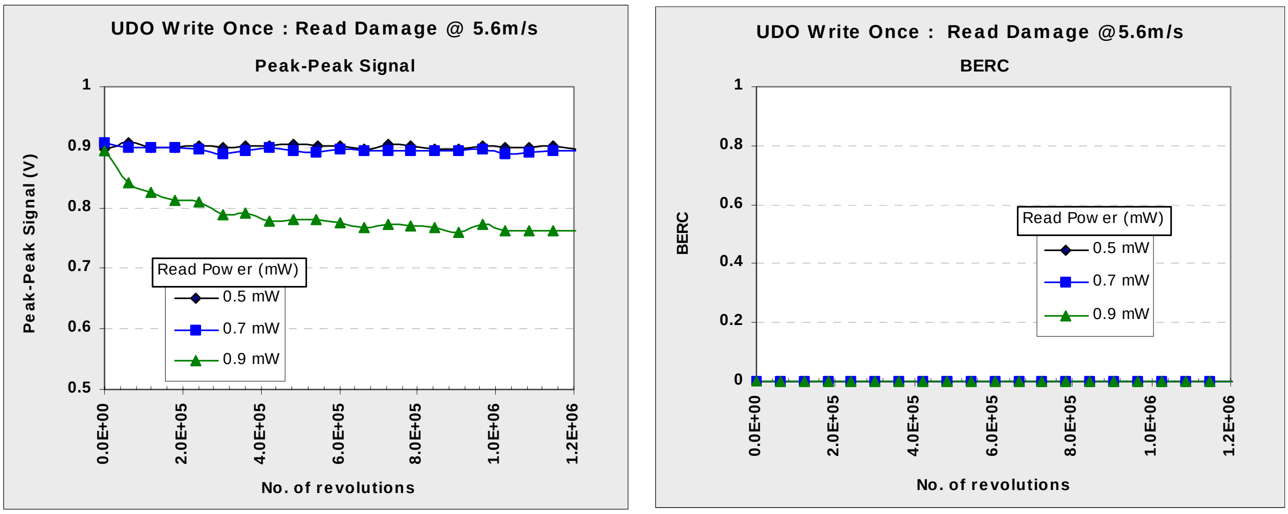


Figure 8: Read stability data at elevated read powers. The nominal read power is 0.4mW. The specification requires the media read lifetime to exceed 10^6 reads at 0.5mW

UDO MANUFACTURE

Ultra Density Optical is likely to be the first commercially available product based upon 405nm blue laser diodes with high numerical aperture. Because of the many new media design features required, including the use of 100µm cover layer disc construction, new thin film stacks, 5¼-inch diameter substrate moulding, etc. an entirely new production facility has been built at Plasmon for UDO (***Figure 9***).

Figure 9: The new UDO manufacturing line at Plasmon Data Systems' factory

SUMMARY

Ultra Density Optical, the next generation 5¼" professional optical data storage technology, has been developed based on phase change technology. The first generation UDO drive incorporates a 405nm blue laser diode with high numerical aperture, NA=0.7 objective lens to realise a capacity of 30GB on a double-sided 5¼", cartridged disc. Both true write once and high cyclability rewritable UDO media have been developed for the multi-function drive. Robust performance with excellent margins has been demonstrated. The roadmap for UDO extends for at least three generations, leading to media capacity of at least 120GB capacity. UDO will be commercially available in the third quarter of 2003.

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