High Density Phase Change Recording for Second Generation Ultra Density Optical

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ABSTRACT

Phase Change is the technology used for Ultra Density Optical (UDO) data storage, designed specifically to provide compliant and secure archival storage for valuable business information. Second generation UDO is currently being developed using phase change recording technology for both Write Once and Rewritable media types. 60GB capacity on a double sided, 130mm disk with a 12MB/s transfer rate is achieved using 405nm, 0.85NA optics and a PRML read channel. In this paper, I shall discuss some of the challenges involved as mark sizes are reduced towards the diffraction limit and illustrate some of the materials science aspects with scanning probe AFM images.

Key words: Phase change, high density, PRML, blue laser, diluted dielectric, fast growth materials

1. INTRODUCTION TO UDO

Ultra Density Optical (UDO)[1] was successfully launched in 2003 as the phase change based successor to Magneto-Optic technology for 5¼” professional optical data storage. From the outset, a clear roadmap for at least three generations was defined, because enterprise customers need a stable platform on which to develop specialized applications. The first generation UDO drive incorporates a 405nm blue laser diode with a 0.7 numerical aperture objective lens to realise a capacity of 30GB in Write Once (WORM), Rewritable (RW) and Compliant (“shreddable”) media formats. This paper describes second generation UDO (UDO2) and some of the issues addressed to develop it. **Table 1** compares key parameters of UDO with other blue laser format data storage products.

	UDO1	**UDO2**	**Blu ray**	**HD DVD**
Capacity (single layer)	30GB (WO & RW)	60GB (WO & RW)	25GB	20GB (RW)
Construction	Double sided	Double sided	Single sided	Single sided
Disk diameter	130mm	130mm	120mm	120mm
Laser wavelength	405nm	405nm	405nm	405nm
Numerical aperture	0.7	0.85	0.85	0.65
Cover layer	100 micron	100 micron	100 micron	0.6mm
Track pitch	370/400nm (WO/RW)	320/350nm (WO/RW)	320nm	340nm
Recording	Land and Groove	On Groove	On Groove	Land and Groove
Channel bit length	99nm	66/62nm (WO/RW)	74.5nm	87nm
Data transfer rate	8MB/s	12MB/s	36Mbps	36.55Mbps
Rotation mode	CAV	CAV	CLV	Zoned CLV
Read channel	ESISIC	PRML	Sliced	PRML

Table 1: UDO specifications compared with Blu ray and HD DVD

2. UDO2 DRIVE TECHNOLOGY

In order to achieve the doubling of capacity from UDO1, UDO2 uses high NA optics (0.85NA compared with 0.7NA for UDO1), dynamic Spherical Aberration Correction (SAC) and a high order Partial Response Maximum Likelihood (PRML) read channel.

Spherical aberration correction (SAC) is required to maintain spot quality with a high NA (0.85) objective lens and disk to disk cover layer thickness variation of more than about 1micron. UDO2 uses a two-lens SAC system. The SAC module adds another complex lens system to the UDO optical design. It requires critical alignment and carefully designed algorithms for firmware positioning of the movable SAC lens. The SAC adjustment is made for each disk load, to compensate for the actual cover layer of the specific disk. The SAC system must also use a very small actuator to fit within the form factor. The UDO2 SAC system implements a novel Piezo stack actuator design. The SAC system can compensate for ±5micron cover layer thickness using a lens stroke of 5mm. It takes approximately 140ms to move the SAC lens across the full 5mm stroke.

Approximately 50% of the capacity gain from UDO1 to UDO2 is achieved by changing the objective lens from 0.70 to 0.85. The remaining 50% capacity gain is achieved by requiring the system to write and read smaller marks. The capacity of 30GB per side for 130mm diameter UDO disks is equivalent to a 120mm Blu-ray disk with capacity of about 29GB. At this channel density the 2T marks become so small that they are not decodable by a standard sliced read channel or the ESISIC read channel[2] used in UDO1 (**Figure 1**). The spot size to mark size ratio for a range of optical storage systems illustrated in **Table 2/Figure 2** shows that UDO2 has a significantly higher spot to mark size ratio than other optical products to date.

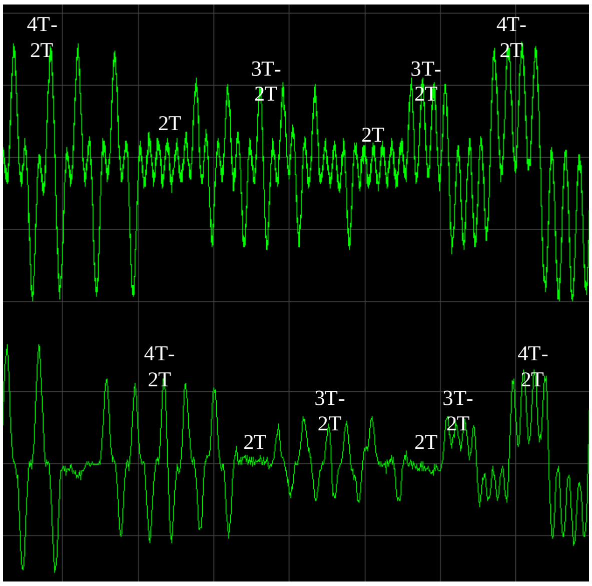


Figure 1: Comparison of 80nm channel bit length (upper trace) typical of Blu-ray with 62nm cbl for UDO2 (lower trace). (Recorded on Pulstec ODU1000)

Format	Laser (nm)	Lens NA	Spot Size (nm)	2T Mark Size (nm)	Ratio of Spot to Mark Size
CD	790	0.45	878	900	0.98
LD6000	785	0.5	785	720	1.09
LD8000	658	0.58	567	486	1.17
DVD	635	0.6	529	440	1.20
UDO1	405	0.7	289	198	1.46
Blu-ray	405	0.85	238	149	1.60
HD DVD	405	0.65	312	174	1.79
UDO2	405	0.85	238	124	1.92

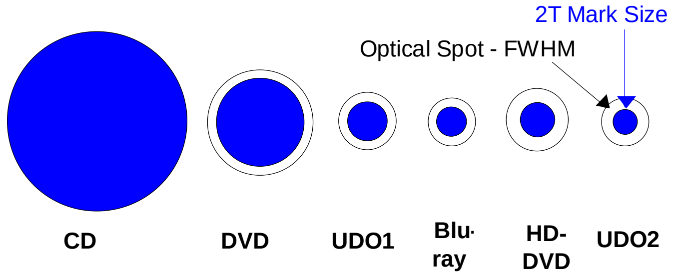


Table 2/Figure 2: Spot to mark size comparison for a range of commercial phase change optical drives.

Accurate write power calibration and write strategy are critical to achieve small marks with a relatively large spot. During read back, the optical spot sees nine channel bits at any given time. The resultant delay for a mark to stop affecting the read signal makes the typical Phase Locked Loop (PLL) impractical. Instead of a PLL, UDO2 uses synchronous data over-sampling and digital signal reconstruction. The effect of larger spot to mark ratio also results in a "smearing" of the read signal, making the smallest marks nearly unresolvable. Classical read channel "slice" based detection is not possible. For data decode, UDO2 uses a high order PRML read channel. This method looks at sequences of samples and uses the optimal Dynamic Programming algorithm (i.e. a Viterbi decoder) in very fast digital logic to compute the most likely channel bit sequence generating the sample sequence. In order to select the most suitable PR scheme for the UDO drive read channel, computer simulation was used[3]. The results shown in **Figure 3**

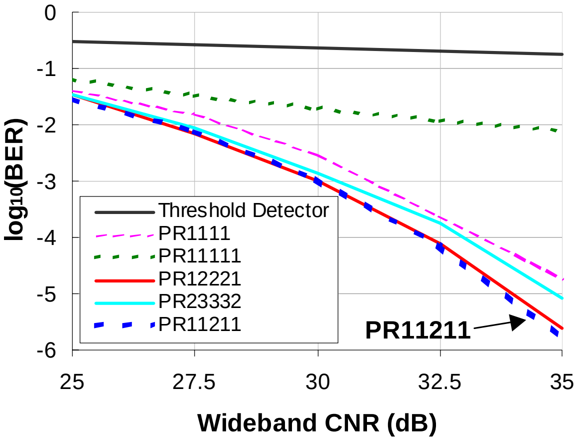
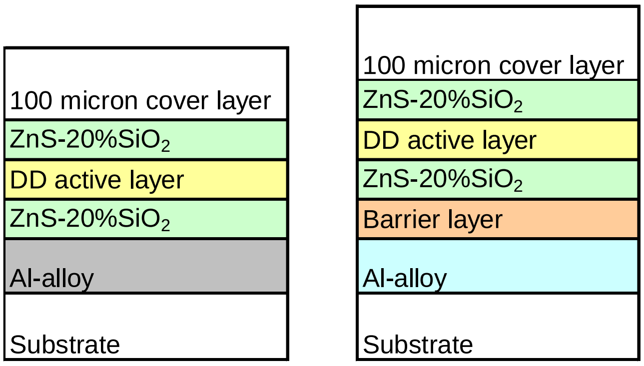


Figure 3: Simulation of the response of different PR schemes to the optical channel (modeled by University of Exeter)

indicated that the most suitable PR schemes were PR11211 or PR12221; the former was selected as the best compromise for implementation complexity, noise immunity and representation of the actual UDO2 system Partial Response (PR). The actual PR of the UDO2 system is more complex than this. As a preprocessing step before decode, the actual response must be mapped to the PR11211 scheme. For this, UDO2 implements a 21 tap adaptive equalizer. This equalizer also helps compensate for some optical spot aberrations in the given drive. So three of the major read channel complexities for UDO2 are the signal reconstructor, the PRML (Viterbi) decoder and the 21 tap adaptive equalizer. As a demonstration of the increased signal processing complexity needed for UDO2 to accomplish this high density, the UDO2 digital ASIC has 2.5 times the number of digital gates as UDO1 (1 Million gates for UDO1 and 2.5 Million gates for UDO2).

3. UDO2 MEDIA TECHNOLOGY: WRITE ONCE (UDO2 WORM)

The phase change material system for UDO1 write once is a diluted dielectric phase change recording material[4] in a four-layer stack (**Figure 4a**). This is also our material of choice for the active layer of UDO2 because of its excellent recording properties, high nucleation density, high contrast and exceptional lifetime performance. However, in order to achieve the higher data densities for UDO2, a number of enhancements were required. **Figure 5** shows the improvements achieved by a series of improvements carried out during preliminary trials at Blu-ray density (23.3GB), 1x recording.



(a) UDO1 WORM **(b) UDO2 WORM**

Figure 4: (a) UDO1 and (b) UDO2 WORM stack construction (not to scale)

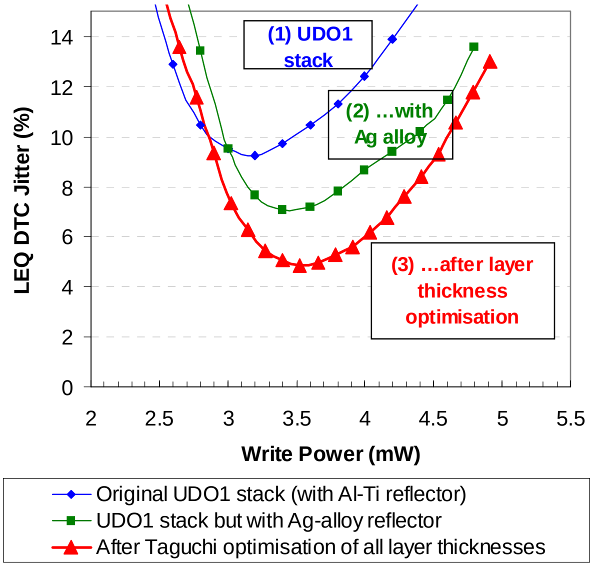


Figure 5: Illustration of steps for initial optimization of the UDO2 WORM stack. Testing carried out at Blu-ray densities, 1x recording on a Pulstec ODU1000 tester

Firstly, the aluminium alloy reflector layer used in UDO1 that forms the foundation of the four-layer stack proved to be too noisy at UDO2 densities, so it became essential to replace it with a lower noise silver alloy. However, silver is also less environmentally stable than aluminium and is especially prone to attack from the sulphur in the ZnS-SiO$_2$ dielectric layers. Therefore it was necessary to add a barrier layer between the dielectric and the silver in order to achieve long lifetime (**Figure 4b)**. Finally, optimization of all the layer thicknesses was used to reduce jitter levels to below 6%, necessary for the read channel to be able to decode the data.

Further optimization of the UDO2 WORM stack was then carried out using the actual UDO2 read channel and **Figure 6** shows the write power margin for the resultant optimized UDO2 WORM media.

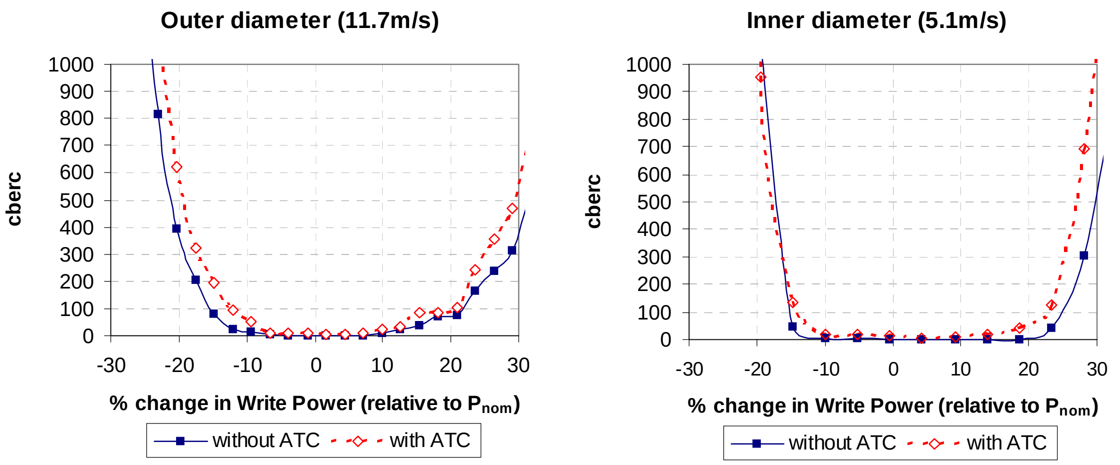


Figure 6: UDO2 Write Once Power margin at outer and inner diameter. *Data is shown both without cross talk (single track writes) and with ATC (adjacent track cross talk where tracks N-1 and N+1 are recorded at 110% of* P_{nom}*)*

Cberc = channel bit error count per sector.

4. UDO2 MEDIA TECHNOLIGY: REWRITABLE (UDO2 RW)

As data densities increase, the key challenge for rewritable media is to achieve high quality recording that is resistant to cross erase[5]: a double challenge since the marks are smaller (and therefore easier to erase) and the adjacent tracks are closer (thus increasing the risk of erasing the data). For UDO media, a further challenge is that of having to record at velocities differing by nearly a factor of two between the inner and outer diameters. This is because UDO is designed as a zoned constant angular velocity product in order to achieve the fast seeks and high data rates required for enterprise applications. These challenges have been met for UDO2 media by a number of changes to the stack. Firstly, in order to prevent cross erase, the layer thicknesses have been tuned to reduce the spreading of heat to adjacent tracks (principally by increasing the reflector layer thickness and reducing the second dielectric). In order to achieve overwrite and interchange performance, the composition of the active layer has been changed to increase the crystallization speed (by increasing the Sb/Te ratio). The exact speed is carefully selected to maintain good performance across all zones.

Figures 7-9 show the recording power margin, read damage resistance and DOW performance for UDO2-RW.

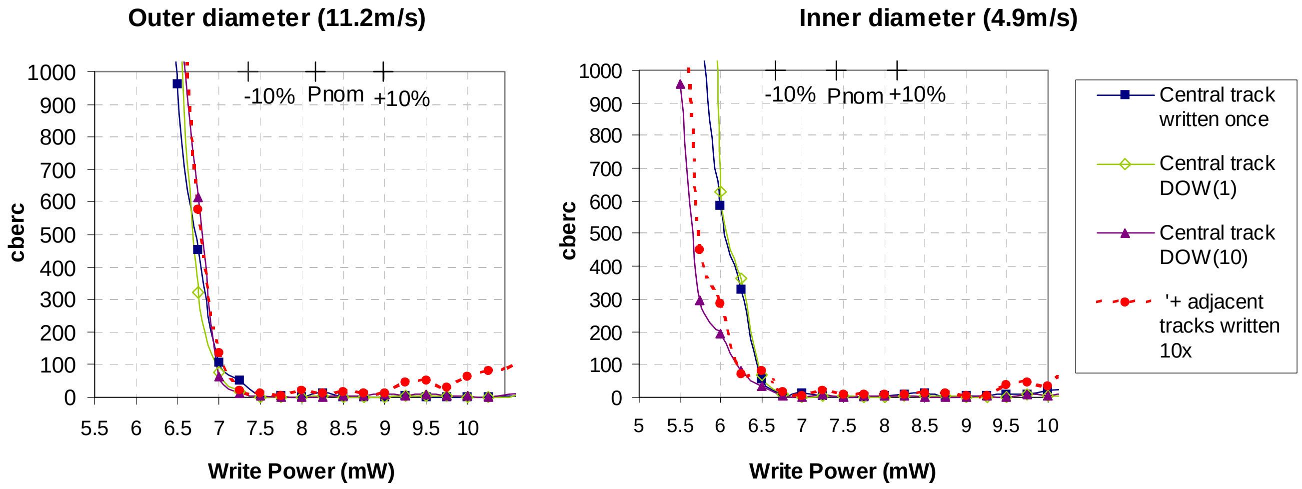
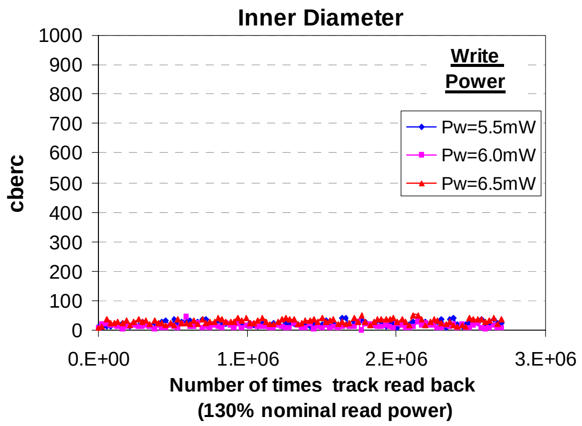


Figure 7: UDO2-RW recording power margin for DOW(0), DOW(1) and DOW(10); then with cross erase/cross talk: adjacent tracks written 10x at 110% of write power. *Cberc = channel bit error count per sector.*



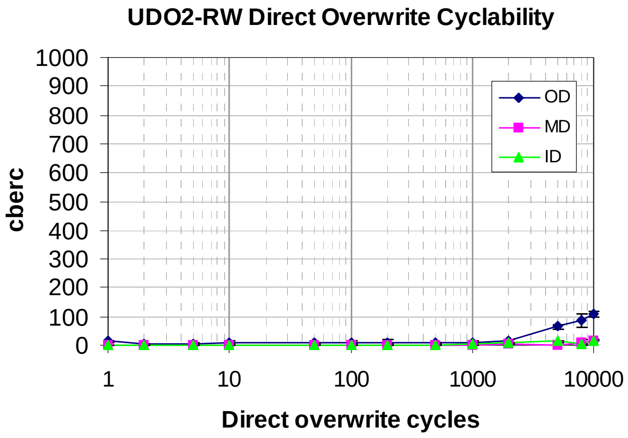


Figure 8: UDO2-RW read damage margins: test carried out at 130% of nominal read power (P_{nom}=0.42mW)

Figure 9: UDO2-RW Direct overwrite (DOW) cyclability showing capability of at least 10,000 cycles

In order to optimize the recording velocity of the active layer by adjusting the Sb/Te ratio in the (In-Ge)-doped Sb-Te eutectic material stack we have found it useful to combine DC erase measurements with conductive atomic force microscopy (c-AFM). The technique of c-AFM is already well known as a convenient method of characterizing the shape of recorded marks in phase change films[6]. For a series of different composition films ("slow", "intermediate" and "fast"), tracks are DC erased with a range of erase powers and the change of the SUM signal measured in the drive read channel after each track has been DC-erased is plotted as a function of linear velocity (**Figure 10**). At low erase powers the SUM signal remains almost constant (consistent with crystal grain growth and annealing). At higher erase powers, the active layer in the centre of the track melts during the DC erase, with regrowth occurring from the edges of the melted region during cooling. It can be seen that for each composition film there is a characteristic velocity above which the SUM signal decreases rapidly: this corresponds to the velocities for which regrowth is too slow for full recrystallisation of the melted area and an amorphous region remains along the centre of the track.

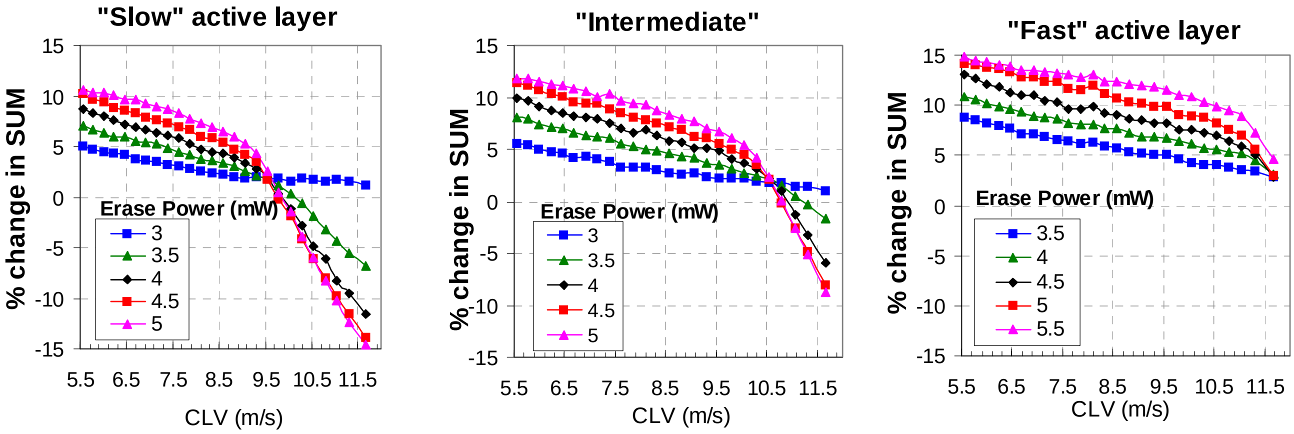


Figure 10: As the Sb/Te ratio is increased in the three samples above, the characteristic cross-over point at which the active layer material speed is insufficient to recrystallise the track following melting at sufficiently high erase powers occurs at higher velocities.

This effect is illustrated by the c-AFM images shown in **Figure 11.** Random data is recorded on alternating tracks at nominal power (P_{nom}). In **Figure 11(a)** the recording speed and the active layer crystallization speed are well matched and the recorded marks are discrete. However, in **Figure 11(b)** the active layer crystallization speed is too slow for the recording velocity and the erase power was sufficiently high that the central region of track between the recorded marks has also amorphised.

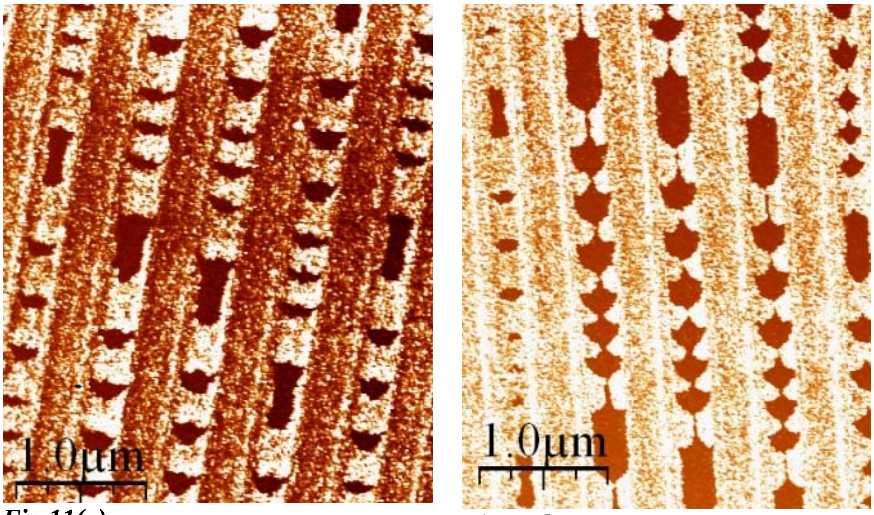


Fig 11(a)

Fig 11(b)

***Figure 11:** Conductive AFM scans of fast growth rewritable media. (a) typical fast growth recording marks (b) amorphisation in the erased region due to too slow an active layer alloy for the recording velocity*

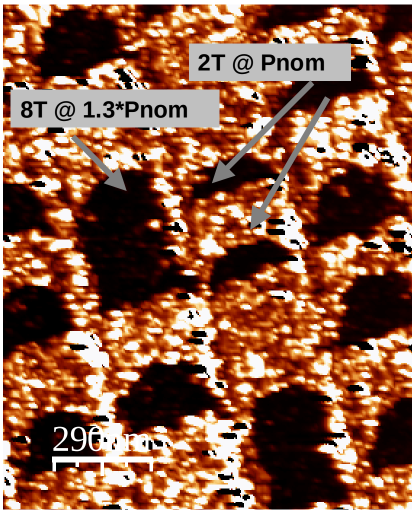


***Figure 12:** To illustrate absence of cross erase. Adjacent tracks recorded at 130% of nominal power*

We have also used c-AFM to visualize and confirm the UDO2 cross-erase robustness results measured in the drive in **Figure 7** by imaging data where alternate tracks have been recorded at extremely high power (**Figure 12**). If cross erase were to occur, the width of the affected marks would be reduced due to crystal growth from the edges resulting from heat spreading from the recording process in the adjacent tracks[5]. However in **Figure 12** there is no reduction in the width of the 2T marks recorded at nominal power even when adjacent tracks have been recorded at extremely high powers 30% greater than the nominal power, illustrating that UDO2 is robust against cross erase.

5. CONCLUSIONS

Second generation UDO has successfully been developed by a combination of drive enhancements and media optimization.

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