Tape in the cloud—Technology developments and roadmaps supporting 80 TB cartridge capacities

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ABSTRACT

Tape, which is the storage of magnetic bits on flexible 0.5” wide media, provides critical data storage needs for the Cloud as evidenced by continued growth in exabyte shipments of tape products. This paper outlines the present storage landscape environment for tape, HDD, and NAND flash, describes the tape roadmap for capacity improvements, and presents recording data on narrow track, 32 channel, TMR tape heads spanning read sensor widths from 1.0 μm to 0.20 μm illustrating the potential for 80 TB cartridge operation. Critically, future improvements in tape areal density and tape cartridge capacity are expected to be achieved from evolutionary developments in head/media technology, not requiring revolutionary developments, such as energy assisted magnetic recording technologies required by HDD strategies.

I. INTRODUCTION

Tape is an essential component for storage in the Cloud. Although tape lacks a consumer component for bit shipments enjoyed by HDD and NAND storage technologies, the ratio of bit shipments between tape and HDD has remained reasonably constant over the last 6 years. Today’s best of breed tape technology is represented by a cartridge capacity of 20 TB in a 20 in² cartridge form factor with an areal density of 12 Gbit/in², 545KBPI, and 24KTPI. Tape, unlike HDD, has achieved technology roadmap goals over the last 5 years so future density goals are credible. This paper will describe the present storage landscape for tape, HDD, and NAND flash; detail the public tape roadmap and show product achievement timelines; and present recording data including SNR performance for tunnel magneto resistive sensors from 1.0 μm widths (20 TB cartridge capacity) to 0.20 μm widths from 32 channel read/write head structures to support future capacity potential in the 80 TB range. This paper will demonstrate that future tape cartridge capacity and areal density improvements suggest achieving 4X improvements in cartridge capacity in the 4-6 year time frame through evolutionary developments in the recording process.

II. THE STORAGE LANDSCAPE AND THE CLOUD

Principal storage technologies used in the Cloud are tape, HDD, and NAND Flash. The storage landscape for these technologies is represented by bits shipped in exabytes (EB), total revenue ($B), average cost per bit ($/GB), and the density of bits or areal density of the associated technology (Gb/in²). When viewed over time, landscape data enable storage clients to view trends and differentiators for the various technologies. Table I shows data for the last two years. These data are assembled from public sources, i.e., quarterly financial reports for HDD and semiconductor manufactures (Seagate, Western Digital, Micron, Samsung) and the Linear Tape Open (LTO) Consortium publications. There are several comments for the tape data in Table I: 1) tape data reflects only LTO media data since enterprise based tape data is not publicly available, 2) 2018 LTO media shipment data is not yet available from the LTO Consortium so 2017 LTO data is used for 2018 data for EB shipments and $/GB
TABLE I. 2017, 2018 Storage Landscape for NAND, HDD, LTO Tape.

|          | 2017     | 2018     | Change |
|----------|----------|----------|--------|
| Bit shipments (EB) |          |          |        |
| LTO Tape  | 44       | 44       | 0%     |
| HDD       | 780      | 938      | 20%    |
| NAND      | 175      | 250      | 43%    |
| Revenue ($B) |          |          |        |
| LTO Tape  | 0.7      | 0.5      | -32%   |
| HDD       | 26.1     | 26.4     | 1.1%   |
| NAND      | 56.5     | 63.2     | 11.9%  |
| Cost/Bit ($/GB) |          |          |        |
| LTO Tape  | 0.0147   | 0.0100   | 32%    |
| HDD       | 0.033    | 0.028    | 16%    |
| NAND      | 0.320    | 0.252    | 21%    |
| Areal Density (Gb/in²) |      |          |        |
| LTO Tape  | 8        | 8        | 0%     |
| HDD       | 1200     | 1200     | 0%     |
| NAND      | 2500     | 3000     | 25%    |

*2018 LTO tape data not reported by LTO Consortium at time of paper publication. 2017 data for EB shipments used for 2018 values.

are calculated assuming equal bit shipments of LTO7/LTO6 media with year-end 2018 pricing and 3) no increase in tape areal density for 2018 is reported since LTO product cycles are 2 years.

The data in Table I show HDD has 76% of bits shipped but only 29% of revenue while NAND has 20% of bits shipped but over 70% of revenue. LTO tape media represents 4% of bits shipped and 1% of revenue. The tape revenue percentage is low for several reasons: 1) only media revenue and not drive and library robotics revenue associated with tape applications is reported, 2) tape has the lowest $/GB, and 3) tape has no consumer-based market. Independent of these issues, tape represents 40 EB of annual bit shipments at $0.01/GB for the storage industry, and primarily for the Cloud.

When landscape data from prior years are combined with the data in Table I historical perspectives of bit shipment growth and revenue growth can be seen. Figures 1 and 2 show the trends in EB shipments and revenue over the last 10 years. Contrary to popular perception manufactured bit growth, i.e., EB growth, over this period is more linear than exponential with growth closer to 25% per year in contrast to perceived information creation growing at 40% per year. Similarly, revenue growth over the last 10 years has been linear, with the majority of revenue attributed to NAND (note that $/GB of NAND are 8X greater than HDD) and NAND revenue exceeding HDD revenue in 2014. From a linear growth perspective, the 10-year trend shows EB shipments increasing by 100 EB annually and revenue increasing by $3.2B annually.

While bit shipment growth and revenue growth are historically dominated by HDD and NAND, the impacts of tape in the Cloud, i.e., differentiations for tape, are seen in the $/GB metric and a more detailed analysis of EB shipments. Figure 3 shows the $/GB trends for the last 10 years for HDD, NAND, and LTO tape media, and Figure 4 shows the ratio of EB shipments between LTO tape media and HDD. For NAND, HDD, and LTO tape media, the $/GB trends are geometric and surprisingly similar with annual reductions of 20%. The differentiator is the ratio of $/GB for these technologies, i.e., LTO tape media has a 2.8X advantage over HDD and a 25X advantage over NAND while HDD has a 9X advantage over NAND; these ratios are reasonably constant over the 10-year period. The value proposition for tape in the Cloud comes from this bit cost advantage. An example of this can be seen by noting that the ratio of tape EB shipments to HDD EB shipments, Figure 4, has remained in the 5% to 6% range over the last 7 years implying that tape storage bit growth is coupled to HDD storage bit growth and hence to the storage of data in the Cloud. This point is not unexpected since data on tape was likely initially on HDD devices.

III. TAPE ROADMAP

Future component level capacities for tape cartridges, HDDs, and NAND chips are projected using technology roadmaps. A critical measure of the technical vitality of a storage technology
is areal density growth or the rate of increase of the number of bits manufactured in a unit surface area of storage media, i.e., on tape, disk, or silicon wafer surfaces. For a fixed component volume, the ability to sustain areal density growth drives estimates of future component capacity. Figure 5 shows the areal density history for NAND, HDD, and LTO tape over the last 10 years. Notable in this plot is that over the last 6 years sustained annual areal density increases for LTO tape have been 25% and this is a factor of 2 greater than HDD annual areal density increases. Tape technology leverages these density increases, with cartridge capacity doubling every two years. More importantly, tape capacity progress over the last 5 years has validated the tape roadmap goals set in 2015 by the Information Storage Industry Consortium (INSIC) hence suggesting that future capacity increases of 4X in 4-6 years are achievable, i.e., the possibility of 80 TB cartridges.

The INSIC 2015 Roadmap goals are summarized in Table II. The metric for doubling cartridge capacity growth every 2 years (41%/yr) is a combination of areal density increases (31%/yr), tape length increase (4%/yr), data management efficiency improvements and error management efficiency improvements (4%/yr). Note that the 2015 INSIC Roadmap represents a blend of both LTO and enterprise tape characteristics, i.e., it is not specifically LTO based. Tape relies on increases in areal density rather than volumetric strategies (4% more tape length annually) to grow component capacity. HDD, in contrast, relies more heavily on volumetric strategies (8 disks going to 9 disks is a 12% increase in media area) to grow capacity. This is attributed to the difficulty the HDD industry is facing in designing recording systems that can overcome the superparamagnetic limit, or more precisely developing a system that can support the thermal stability of small bit cells using energy assisted writing strategies. Tape, with bits cells 80X larger in area that HDD cells, does not yet have this issue.

Relevance of the 2015 Tape Roadmap can be seen by comparing areal density, Figure 6, and cartridge capacity, Figure 7, for products produced over the last 5 years. In both cases roadmap and actual product characteristics for capacity and areal density are in good agreement. Both LTO and enterprise products are shown in the figures.
From the above discussion, it is apparent that tape technology, based on roadmaps and recent history, has growth paths in cartridge capacity that will be cost effective since areal density growth rates continue at > 25% annual rates. This point further establishes the importance of tape in the Cloud.

IV. TAPE TECHNOLOGY ENABLERS FOR 80 TB CARTRIDGE CAPACITY

Key strategies for enabling cartridge capacity growth include improvements to the media and to the recording system itself. These are inter-related, and so we begin with a discussion media and a head-media contact implication. Media improvements include increasing SNR (e.g., by reducing particle volume), which enables growth of area density, and thinner substrates for greater media length or volumetric density. But also critical is reducing magnetic spacing between heads and media. An implication is that both media magnetic layer thickness and roughness must be reduced over time. HDD head-media spacing is now of the order of a nanometer (nm) and is approaching contact, whereas spacing in current TAPE products is of the order of 20-30 nm and so has considerable room for improvement. A key feature of current tape drives is the write heads are physically separate from the read head and thus able to support lower spacing. But because heads run in continual contact with the tape media, the tape read head requires a unique strategy for mitigating wear and other effects over the life of the head.

Tape media of necessity contains wear particles (aluminum oxide) that may not affect the roughness or Ra of the media, but nonetheless may, particularly if clustered, have a propensity to scratch the delicate surfaces of the read sensors. Thus, in addition to pre-recession and coating strategies previously described, a strategy for mitigating shorting due to scratches was devised. This resulted in the sensor structure shown schematically in Figure 8. The upper portion shows a conventional tunnel valve device having shields that also serve as electrical contact leads. The lower portion shows the new sensor, in which alumina Insulating layers are inserted between the shields and the leads connected thereto. Note that current must flow laterally along the lead layer. Modeling was used to optimize the film thicknesses in this design, in which resistance drop due to current flow around the insulation layers, including laterally inward from the sides of the sensor (not shown in the figure), is less than approximately 10%. This is acceptable, given the high output of the tape TMR devices. This sensor is deployed in the IBM TS1160 20TB tape drive product, in which propensity for shorting from media defects has been reduced by more than a factor of 3.

Also, key to enabling capacity growth are improvements to the design of the recording system itself. In addition to addressing media, head-media spacing, and managing tribology in a contact recording environment, capacity growth demands increases in both
track and linear densities. As for the HDD industry, and as is well known in magnetic recording in general, track density is key for areal density growth. In simple terms, a 50% increase in track density may result in up to a 2dB loss in SNR due to requiring a reader having a smaller trackwidth, whereas a 50% increase in linear density would result in a significantly greater loss in SNR due to non-linear roll-off in head output vs linear density. To facilitate investigating opportunities to increase track density for future products, a series of 32 channel read heads was fabricated and tested in standard TS1160 product drives. For the study, the tunnel valve resistivity was set to 10 Ω-μm² (on wafer) to produce heads having resistances in range of 50 to 300 ohms, which is compatible with the drive read electronics. Reader shield-to-shield spacing was 88nm, which supports linear density up to 600 KBPI. Sensors are of the design shown in Figure 8. In addition, an improved electronic lapping guides strategy was implemented for achieving better control of stripe heights, which is approximately ±100nm. In future tape heads, HDD lapping strategies will be implemented for reducing stripe height variation to ±10nm or better. This is important for all sensors and in particular for future narrow sensors. Tracks widths fabricated were 900, 800, 700, 600, 500, 400, 250 and 200nm. SNR test results, relative to the 20TB sensor width of 1000 nm, are shown in Figure 9. Media is the 20TB enterprise BaFe media. Linear density is the 20TB product linear density of 545 KBPI. The data shown are the median channel SNR values for 2 heads at each trackwidth. All 32 tracks on all the heads functioned properly with very good longitudinal stabilization biasing.

In addition to the study above, an initiative to explore writer transducer improvements led to a design in which the pole tips having high moment CoFe films adjacent to the write gap, and in which the write gap length is reduced from 150nm to 105nm. The results are encouraging, as SNR is approximately 0.3dB improved and edge writing is reduced approximately 30% with the smaller write gap. Further, servo readers in the new writers are an optimized tunnel valve design, which overcomes limitations posed by previous generation writer module GMR servo reader sensors, which have lower output.

V. CONCLUSION

In summary, near term tape strategies, as detailed by the 2015 INSIC Tape Roadmap, to achieve 80 TB tape cartridge capacities exist and demonstrate that tape technology will remain a critical storage component for the Cloud. Moreover, tape roadmap goals directed to doubling cartridge capacity have been achieved over the last 5 years of product development. Tape, with a bit cell area ~ 80X greater than HDD, is able to rely on traditional HDD head technology since it is not limited in areal density increases by the super-paramagnetic limit and hence is not required to incorporate energy assisted transducer developments to increase cartridge capacity but rather is modifying existing transducer technology to be compatible with contact recording.

REFERENCES

1. R. E. Fontana et al., “The impact of areal density and millions of square inches (MSI) of produced memory on petabyte shipments of TAPE, NAND flash, and HDD storage class memories,” 2013 Symposium on Mass Storage Systems and Technologies (MSST), ID 13554009, pp. 1–8 (2013).
2. R. E. Fontana and G. Decad, “Moore’s law realities for recording systems and memory storage components: HDD, tape, NAND, and optical,” AIP Advances 8, 056506 (2018).
3. 2015 International Magnetic Tape Storage Roadmap, http://www.insic.org/news/2015%20roadmap/15%20index.html.
4. M. Lantz et al., “123 Gb/in² recording areal density on barium ferrite tape,” IEEE Transactions on Magnetics 51(11), 3103304 (2015).
5. R. G. Biskeborn et al., “TMR tape drive for a 15 TB cartridge,” AIP Advances 8, 056511 (2018).