TOSHIBA

Multi-Level Cell NAND Flash Performance for Consumer Applications Application Note

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TOSHIBA AMERICA ELECTRONIC COMPONENTS, INC.

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1. Introduction

The purpose of this application note is to examine the data storage performance requirements of today's digital consumer applications and whether multi-level cell (MLC) NAND Flash memory can meet those requirements. This includes recent research from Toshiba America Electronic Components, Inc. (TAEC) that outlines the bandwidth requirements for many typical consumer applications. Theoretical performance characteristics of both single level cell (SLC) and MLC NAND Flash memory are then compared against these application requirements. This data demonstrates that the latest MLC NAND Flash chips, developed by Toshiba Corp. (Toshiba), go well beyond the performance necessary to support the data storage requirements of most consumer applications.

2. MLC and SLC NAND Flash Memory: Performance Characteristics

For those unfamiliar with the technology, MLC NAND Flash allows each memory cell to store two bits of information, compared to one bit per cell for SLC NAND Flash. This results in a larger capacity and lower bit cost. While SLC NAND Flash may be more appropriate for some applications where high performance is required, the difference will not affect many common consumer applications, including most digital cameras. MLC NAND provides a very competitive level of performance and makes high-density NAND Flash cards more affordable, accounting for its growing popularity among consumers. The following is an explanation of how MLC NAND Flash performance differs from that of SLC NAND Flash.

2A. Extended Use

MLC NAND Flash can certainly stand up to extended use for many consumer applications, such as digital photography, MP3 audio players, USB drives, and other typical data storage. MLC NAND Flash does have a different rating for the number of write/erase cycles in comparison to SLC NAND Flash. Currently, Toshiba 90 nanometer (nm) SLC NAND Flash is rated at approximately 100,000 cycles, and the rating for Toshiba 90nm MLC NAND Flash is approximately 10,000 cycles. While there are applications for which SLC NAND Flash with its higher write/erase cycle rating is better suited, the 10,000 cycles of MLC NAND Flash is more than sufficient for a wide range of consumer applications, from storing documents to digital photos. For example, if a 256 megabyte[1] (MB) MLC NAND Flash-based card can typically store around 250 pictures from a 4-megapixel camera (which is a conservative estimate), its 10,000 write/erase cycles, combined with wear-leveling algorithms in the controller, will enable the user to store approximately 2.5 million pictures within the expected useful life of the card. This total is far beyond the average number of photos taken by a typical user that the difference in endurance is not significant for this specific application. A significant portion of the NAND Flash-based memory cards available today are based on MLC NAND Flash, and the continuing rapid growth of this market is an indication that the performance is meeting consumers' needs. For a more general application such as a USB drive, the 10,000 write/erase cycles would enable the user to completely write and erase the entire contents once per day for 27 years, well beyond the life of the hardware.

2B. Capacity and Additional Circuitry

The additional circuitry required to implement MLC NAND Flash is relatively minimal. A 4 gigabit[2] (Gb) MLC NAND Flash chip provides approximately 1.96 times greater density than a 4Gb SLC NAND chip. The more relevant question for the consumer is: "What density is available in a removable Flash memory card today?" Currently, the highest density MLC NAND Flash in production is 8Gb (which enables a 1GB[3] SD™ Card), whereas the highest density SLC NAND Flash in mass production is 4Gb (which enables a 512MB SD Card). The market demand for higher removable storage densities makes the lower-cost, higher-density MLC NAND card more attractive to users and continues to enable the emergence of new applications. The minimum specified capacity of 4Gb SLC NAND is 542, 834, 688 bytes, compared to 1,064, 042, 496 bytes for 4Gb MLC NAND. This equates to a factor of approximately 1.96 times greater density.

2C. Read/Write Performance

The additional capacity available with MLC NAND Flash does come with a tradeoff in slightly reduced read/write performance. For Toshiba large block NAND manufactured on 90 nanometer (nm) process technology, the MLC version has a read speed of 108Mbps (13.5MB/s), compared to a read speed of 128Mbps (16MB/s) for the SLC version. The write speed for this large block MLC NAND Flash is 20 Mbps (or 2.5MB/s) while a comparable SLC NAND Flash has a write speed of 46Mbps (or 5.7MB/s). The following performance evaluation illustrates that in many applications, the transfer rates are still sufficiently fast to be unnoticeable to the user (see Figure 1: Theoretical NAND Flash Component Performance).

	Application	Bandwidth	LB MLC Write	LB SLC Write	LB MLC Read	LB SLC Read	Comments
Digital Video	MPEG 2, 720X480	6-8Mbits/s					"DVD" quality
	MPEG 2, 1280X720	19-20Mbits/s					"HD" quality
	WMedia 9, 720X480	2-4Mbits/s	20Mbits/s	46Mbits/s	108Mbits/s	128Mbits/s	"DVD" quality
	WMedia 9, 1280X720	5-8Mbits/s					"HD" quality
	H.264/MPEG4 AVC, 720X480	3-4Mbits/s					"DVD" quality*
	H.264/MPEG4 AVC, 1280X720	6-7Mbits/s					"HD" quality*
	*50-70% smaller than MPEG-2						
Music	MP3, 128 kbps	.124Mbits/s	20Mbits/s	46Mbits/s	108Mbits/s	128Mbits/s	Near "CD" quality
	WMA, 128 kbps	.124Mbits/s					Near "CD" quality
	Theoretical NAND Performance		2.5MB/s	5.7MB/s	13.5MB/s	16MB/s	
			File Write Times (sec.)		File Read Times (sec.)		
Data Storage**	Average Word file	159kB	0.064	0.028	0.012	0.01	
	Median Word file	45kB	0.018	0.008	0.003	0.003	
	Max. Word file	68MB	27.2	11.9	5.04	4.3	
	Average Excel file	528kB	0.21	0.09	0.039	0.033	
	Median Excel file	35kB	0.014	0.006	0.003	0.002	
	Max. Excel file	137MB	54.8	24	10.1	8.6	
	Average PowerPoint file	1.18MB	0.47	0.2	0.09	0.07	
	Median PowerPoint file	239kB	0.1	0.04	0.02	0.02	
	Max. PowerPoint file	399MB	159.6	70	29.6	24.9	
	**Study based on thousands of files on TAEC server, March 2004						

Sources: mp3-cdburner.com, envivio.com, Microsoft, TAEC server analysis March 2004
NAND performance based on 90nm LB MLC and SLC devices

Figure 1. Theoretical NAND Flash Component Performance

3. MLC NAND Performance Research Results

A recent study analyzed the performance characteristics of both SLC NAND Flash and MLC NAND Flash. The results indicated that the bandwidth requirements for many typical consumer applications, from playing music to streaming digital video, can be achieved by using MLC NAND Flash memories. In fact, the most recent Toshiba MLC NAND Flash memory chips significantly surpass the reliability and performance requirements of numerous consumer electronics applications as described below.

3A. Increased Bandwidth

The increased bandwidth of the latest Toshiba MLC NAND Flash exceeds the minimum read and write requirements of some file formats by as much as a factor of 20, going beyond the necessary functionality and reliability for the majority of today's consumer electronics applications. Toshiba recently introduced the semiconductor industry's first 4Gb single-die MLC NAND chip, produced using 90nm process technology. The new high-density MLC NAND Flash chips enable faster write performance by implementing advanced design concepts and adjusting the control system of the memory cell (see Figure 1: Theoretical NAND Flash Component Performance).

3B. Extensive Analysis

Based on extensive internal and external analysis, combined with published bandwidth requirements for various digital video and music formats, the bandwidth of Toshiba's MLC NAND Flash can offer more than sufficient performance to support the minimum read-and-write specifications of various digital video file formats, including MPEG2, MPEG4 Advanced Video Coding (AVC) or H.264, Windows Media® 9.0 files; standard digital audio file formats, including MP3 and WMA files; and a range of Microsoft® Office applications, including Excel, Word, and PowerPoint® files (see Figure 1: Theoretical NAND Flash Component Performance).

3C. DVD-Quality Digital Video Applications

The latest MLC NAND Flash from Toshiba delivers read and write times of 108 megabits per second (Mb/s) and 20 Mb/s, respectively. This is more than sufficient to support DVD quality video applications, which require a bandwidth of 6Mb/s to 8Mb/s for MPEG2, 720 x 480 digital video[4], 2Mb/s to 4Mb/s

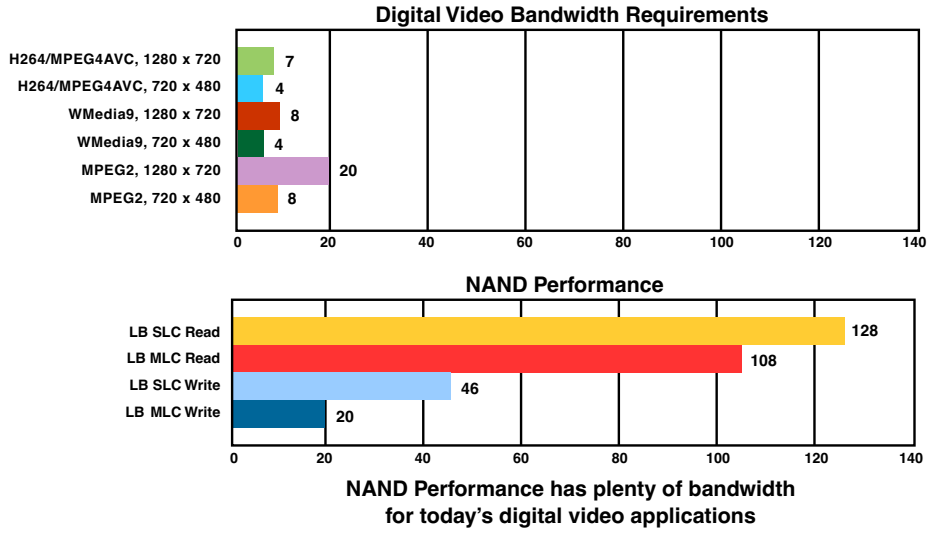

Figure 2. Digital Video Performance

seconds for Windows Media 9 digital video[4] and 3Mb/s to 4Mb/s for H.264/MPEG4 720 x 480 digital video[5]. MLC NAND Flash also meets or exceeds the bandwidth requirements for high definition DVD (HD-DVD) video, which are 19Mb/s to 20Mb/s for MPEG2, 1280x720 video[4], 5Mb/s to 8Mb/s for Windows Media 9 1280 x 720 video[4] and 6Mb/s to

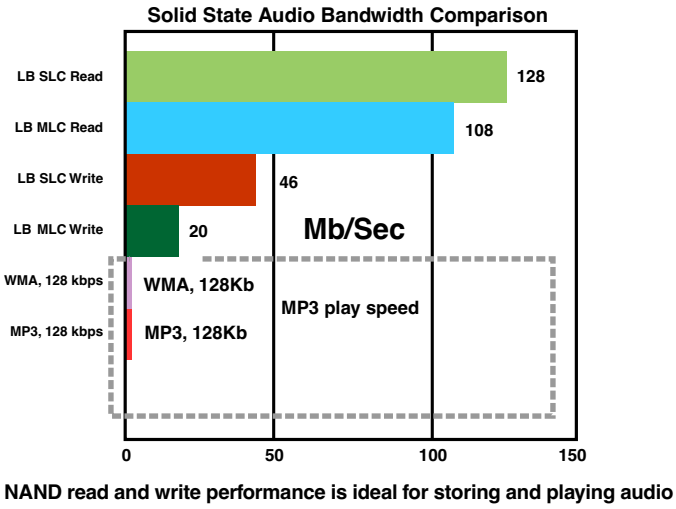

Figure 3. Music Bandwidth Comparison

7Mb/s for H.264/MPEG4 1280 x720 video[6], although the bandwidth requirement for HD-DVD with MPEG2 compression (one of several emerging formats for HD-DVD) approaches the maximum throughput of the MLC NAND Flash (see Figure 2: Digital Video Performance).

3D. Digital Music Storage and Playing

Storing and playing digital music is another application for which MLC NAND Flash is well suited. The minimum bandwidth to play either MP3[7] or WMA[7] files is approximately 128 kilobits/second; a small fraction of the 108Mb/s read speed that can be achieved with Toshiba large block MLC NAND Flash. A typical MP3 song requires about 4MB of memory to store. Since MLC NAND Flash offers a write speed of approximately 20Mb/sec (2.5MB/sec), it can take less than 2 seconds to download a song. Once again, the specifications of Toshiba MLC NAND technology exceed those required for the downloading and playback of digital music (see Figure 3: Music Bandwidth Comparison).

3E. Office Application Data Storage Performance

For typical office applications, such as Microsoft Office, Excel, PowerPoint and Word, Toshiba MLC NAND Flash can again deliver sufficient bandwidth for the reading and writing of these files. As a result, MLC NAND Flash performance is suitable for USB drives. Expressed in megabytes per second (MB/s), the read and write speeds of Toshiba large block MLC NAND are 13.55 MB/s and 2.5 MB/s, respectively. To test the time required to download typical size Word, Excel and PowerPoint files, TAEC simulated files stored on servers, determining the media, average and maximum file sizes for each application to get a typical representation of documents in an enterprise environment. The average size documents

were 159 kilobytes[8] (kB), 528kB, and 1.18MB, respectively, for Word, Excel and PowerPoint documents. For these documents, the time required to read or write the average Word, Excel, and PowerPoint document is less than a second, which is more than sufficient to satisfy today's consumer and business users of USB Flash Drives for typical business applications (see Figure 1: Theoretical NAND Component Performance for details on document read and write times).

A summary of typical SLC versus MLC NAND applications is shown in Figure 4.

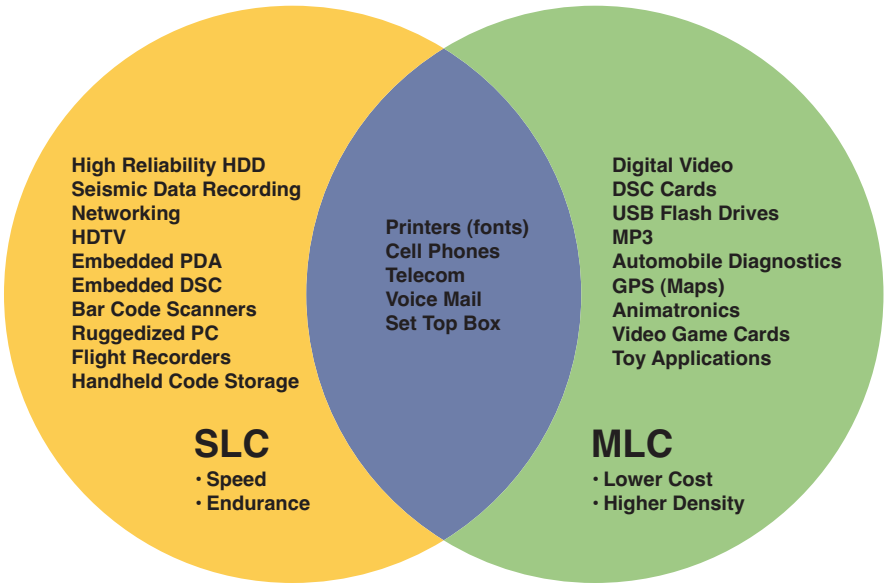

Figure 4. SLC/MLC NAND Applications

1 When used herein, megabyte and/or MB means 1,024x1,024 = 1,048,576 bytes. Usable capacity may be less. For details, please refer to specifications.
2 When used herein, gigabit and/or Gb means 1,024x1,024x1,024 = 1,073,741,824 bits. Usable capacity may be less. For details, please refer to specifications.
3 Usable capacity may be less. For details, please refer to specifications.
4 Microsoft Windows Media 9 http://www.microsoft.com/windows/windowsmedia/9series/codecs.aspx
5 "Overview of the H.264/AVC Video Coding Standard," IEEE Transactions on Contents on Circuits and Systems for Video Technology, July 2003.
6 "Sand Video Offers H.264 Decoder Core Licenses," EE Times UK, July 21 2003.
7 mp3-cdburner.com/audio-format-Comparison-Table.shtml
8 When used herein, kilobyte and/or kB means 1,024 bytes. Usable capacity may be less. For details, please refer to specifications.

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