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Technical White Paper

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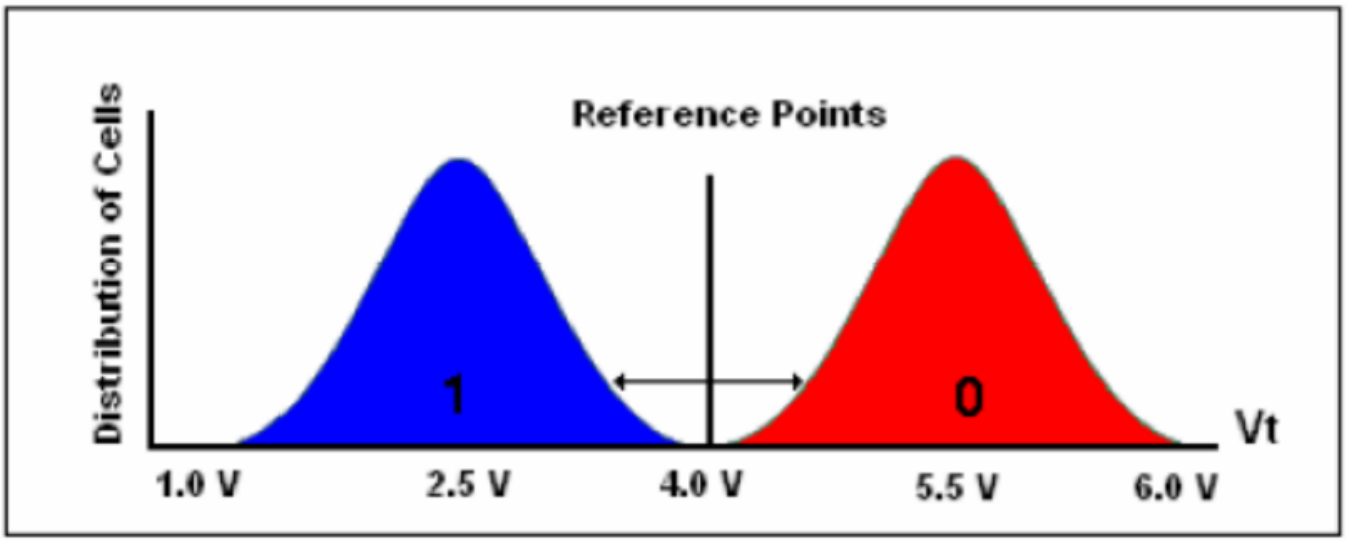
Flash type comparison for SLC/MLC/TLC and Advantech's Ultra MLC technology



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Introduction

Flash memory is a non-volatile storage element that can be electrically programmed/re-programmed and erased. As technology continuously advances, the demands for greater density and better performance with flash memory become large as well.

The purpose of this paper is to provide an overview on the difference of NAND flash types for SLC, MLC & TLC comparison and also Advantech's Ultra MLC (uMLC).

Single-Level Cell (SLC) Flash

As the name suggests, SLC Flash stores one bit value per cell, which basically is a voltage level. The bit value is interpreted as a "0" or a "1". Since there are only two states, it represents only one bit value.

As seen in below Table, each bit can have a value of "programmed" or "erased."

Value	State
0	Programmed
1	Erased

Table1: SLC Levels

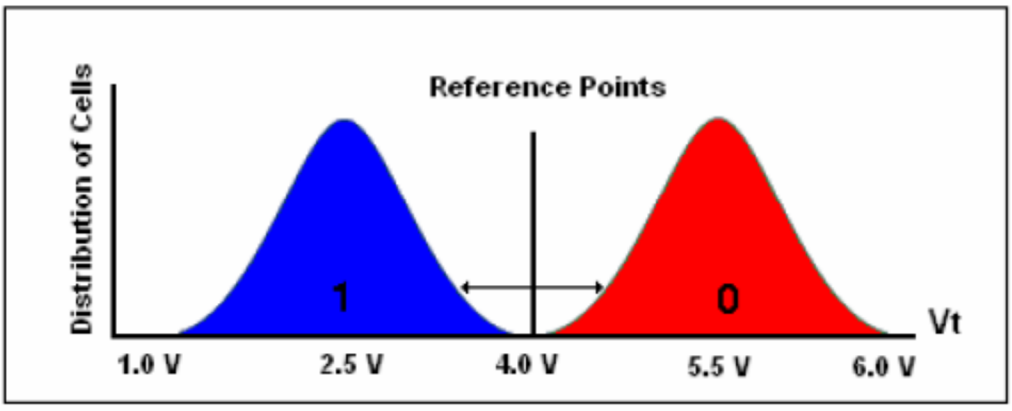


Figure 1: Voltage Reference for SLC

Multi-Level Cell (MLC) Flash

As the name suggests, there are multiple values that an MLC cell can represent. The values can be interpreted as four distinct states: 00, 01, 10, or 11.

Value	State
00	Fully Programmed
01	Partially Programmed
10	Partially Erased
11	Fully Erased

Table2: MLC Levels

These four states yield two bits of information. As seen in below table, the value of the two bits range from fully programmed to fully erase. Therefore, 2 bits data can be stored in each cell.

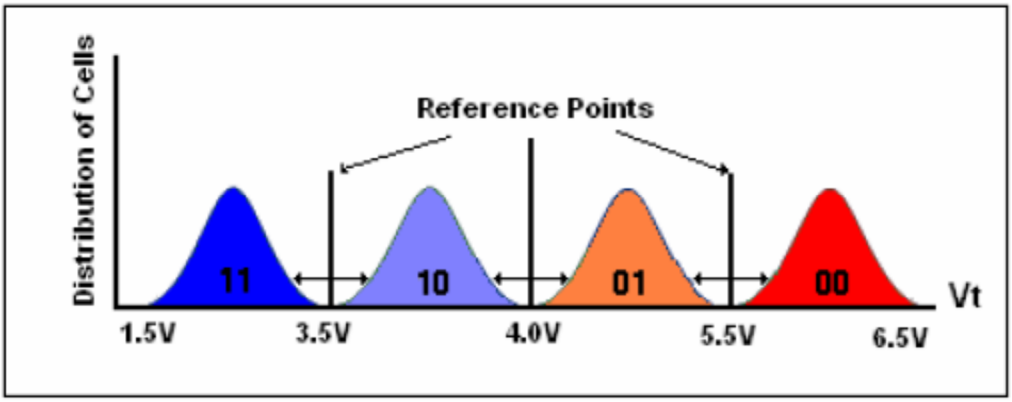
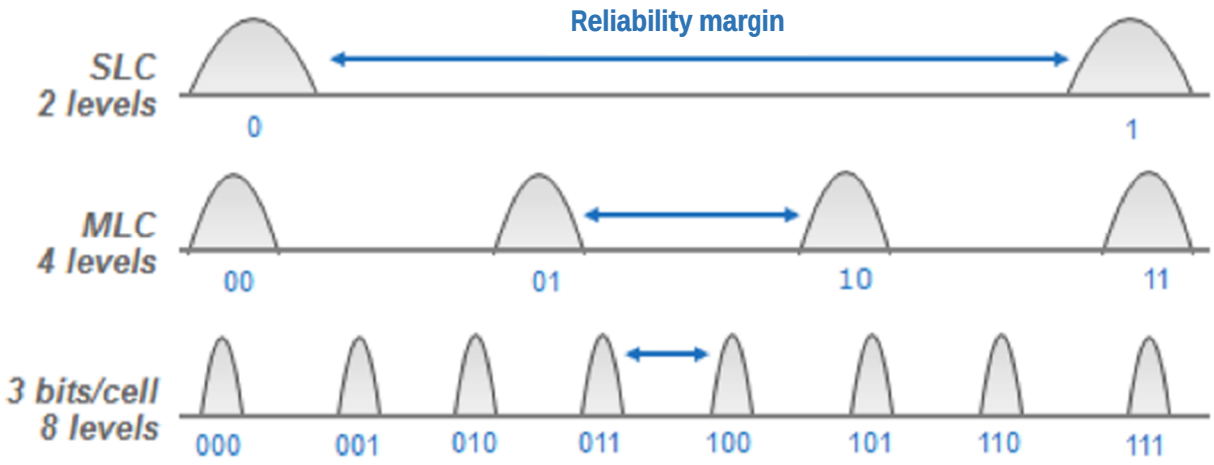


Figure 2: Voltage Reference for MLC

Triple-Level Cell (TLC) Flash

The values can be interpreted as 8 states: 000, 001, 010, till 111 as below. Hence, every single cell can store 3 bits data to increase the capacity.

However, the performance and reliability from SLC to MLC then to TLC will decrease significantly due to the more the voltage levels, the more error, misjudge and bad block will occur due to the reliability margin become less as shown in below Figure.



SLC/MLC/TLC Comparison Summary Table

	SLC	MLC	TLC
Bits per cell	1	2	3
P/E Cycles	100,000	3,000	1,000
Read Time	25 μs	50 μs	~75 μs
Program Time	200-300 μs	600-900 μs	~900-1350 μs
Erase Time	1.5-2 ms	3 ms	4.5 ms

Source: http://www.anandtech.com/show/6337/samsung-ssd-840-250gb-review/2

Conclusion

Since there are different NAND Flash types in the SSD market, it is very important to understand the application and usage of SSD. For industrial or mission critical application, due to the low endurance and performance of current TLC, it is not suggested for industrial focus customers. Again, it is important to evaluate what type of flash memory that customer's application needs. If performance and durability are essential, SLC Flash incorporated. If low cost and high density are essential, MLC flash is the right choice.

However, TLC is more suitable for commercial or end consumer usage instead of industrial focus due to the endurance limitation.

UltraMLC (uMLC) Technology Introduction

Because MLC flash stores 1 more bit at each cell than SLC flash does, MLC provides higher density and lower bit-cost. Unfortunately, nothing comes for free – the trade off for cost-saving is greater power consumption and less endurance, due to more voltage levels required and technology limitation. It is common to see that SLC flash is used in industrial / mission critical applications, whereas MLC flash is used in commercial applications.

Although SLC flash is more endurable and provides better performance than MLC flash does, cost is still an issue to users. What if we could have the best of the both worlds – a new gene that delivers greater performance and endurance, but yet at the same time, is an economical solution?

The answer is yes – Ultra MLC (uMLC)

The very idea with Ultra MLC (uMLC) is that MLC flash consists of a number of fast and slow pages, and only fast pages will be used for programming when using Ultra MLC (uMLC). One can think of Ultra MLC (uMLC) as an extended version of MLC flash. Below table and figure explain the concept of Ultra MLC (uMLC): The first and second bit of a memory cell corresponds to a fast and slow page, respectively, as shown in Table 1 (Left). Since we program fast pages with Ultra MLC (uMLC), only the bits highlighted in red in Table 2 (Middle) will be used.

MLC Flash	
1st Bit (Fast)	2nd Bit (Slow)
1	1
1	0
0	1
0	0

Ultra MLC Flash	
1st Bit (Fast)	2nd Bit (Slow)
1	1
1	0
0	1
0	0

SLC Flash
Bit
1
0

Table: Cell Content for MLC (Left), uMLC (Middle) and SLC (Right), Respectively

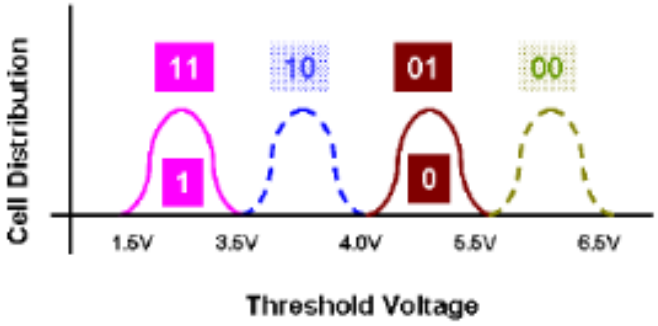
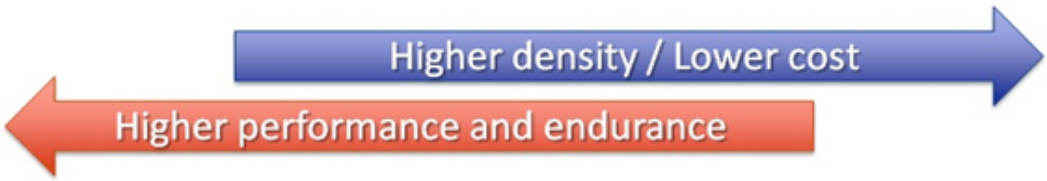


Figure: Cell Distribution vs. Threshold Voltage for uMLC

When the two bit-sets (10 and 00) from MLC flash are discarded, the bit data from Ultra MLC (uMLC) is almost identical to that with SLC flash. In above figure, the threshold voltage ranges that correspond to 10 and 00 will be discarded, leaving the ones for 11 and 01. Differentiating the amount of charges inside the floating gate becomes easier, since a more separate cell distribution reduces the chance to misjudge the threshold voltage for each cell.

SLC/ uMLC/MLC/TLC Comparison Summary Table

	SLC	uMLC	MLC	TLC
Bits per cell	1	1	2	3
P/E Cycles	100,000	30,000	3,000	1,000
Read Time	25 µs	~42 µs	50 µs	~75 µs
Program Time	200-300 µs	~450 µs	600-900 µs	~900-1350 µs
Erase Time	1.5-2 ms	~4.5 ms	3 ms	~4.5 ms



Source: http://www.anandtech.com/show/6337/samsung-ssd-840-250gb-review/2

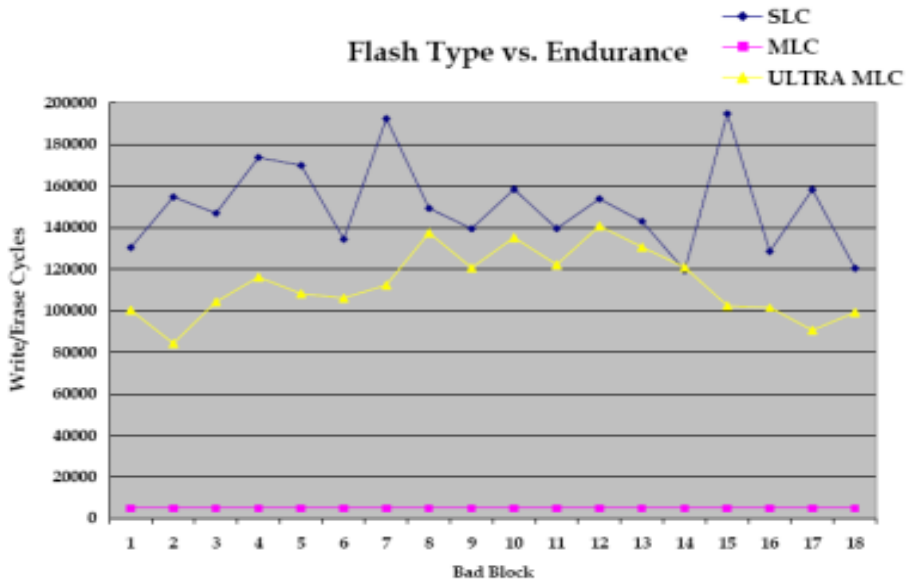


Figure: Endurance Comparison among SLC, MLC and Ultra MLC

Testing Methodology

We program and erase only one block at a time until it becomes unusable (later bad block) and then move on to the second block so on and so for.

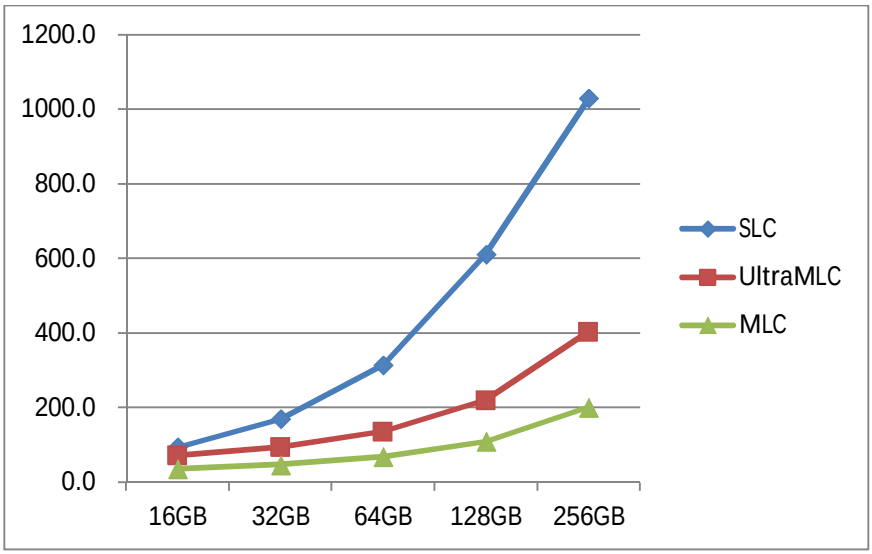
Observations

In below Figure, it is obvious to see that Ultra MLC (uMLC) outperforms MLC in terms of withstanding a greater amount of usage. In general, MLC endurance is considered to be about 3K times, and our previous experiments have allowed us to conclude that endurance of Ultra MLC (uMLC) is at least 10 times greater than that of MLC.

	Program / Erase Cycle	Cumulative Block Failure Rate (%)
MLC Flash	3,000	Less than 0.04
Ultra MLC Flash	30,000	

Cost comparison

Ultra MLC (uMLC) basically is still using MLC flash but sacrifice 50% of the storage capacity to greatly increase the durability, hence, the cost is about x2 times of MLC but still much cheaper compared with SLC flash. Below is the cost estimation between SLC, uMLC & MLC.



Cost estimation with different capacities

Conclusion(s)

Ultra MLC (uMLC), a part of the MLC family has been proved to provide better performance and greater endurance by programming only fast pages. Our experiment has shown that the read/write performance is improved. Additionally, endurance of Ultra MLC (uMLC) is at least ten times greater than that of MLC, which is used by programming both fast and slow pages. We believe that Ultra MLC (uMLC) is the most economical alternative for Industrial NAND flash applications when it comes to stable and cost-efficiency requirements.