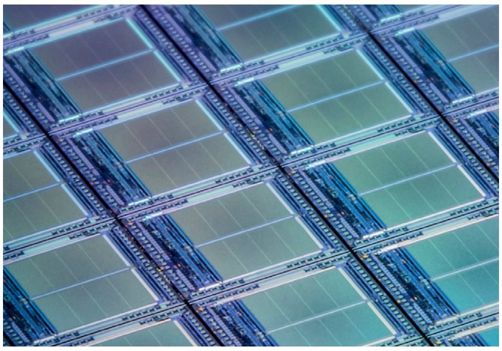
White Paper

iSLC – Claiming the Middle Ground of the High-end Industrial SSD Market



Executive Summary

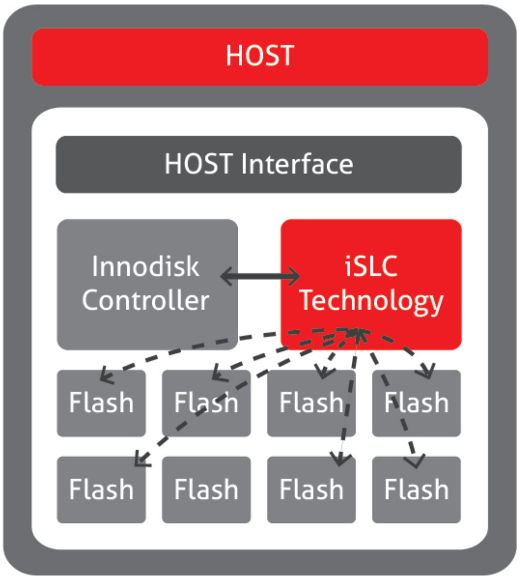
iSLC is a NAND flash technology designed to optimize the balance between cost and performance. The firmware technology is built on the framework of multi-level cell (MLC) NAND flash. MLC NAND flash cells are made to hold one bit per cell instead of two, effectively mimicking single-level cell (SLC) NAND flash.

iSLC is a hybrid between MLC and SLC technology, where performance is closer to SLC and endurance is significantly higher than MLC. The price roughly falls between MLC and SLC products.

The program/erase (P/E) cycle limit for iSLC is around 20,000, while MLC is 3,000 and SLC ranges from 60,000 to 100,000. Burn tests show iSLC solid state drives (SSD) far surpass their stated P/E cycle limitations without data loss or data failures.

A burn test comparison between an iSLC an MLC device showed a significant difference in the number of error checking and correction (ECC) bits (iSLC 15, MLC 40). Write performance tests indicate that iSLC is about 10% slower than SLC and around twice as fast as MLC.

Introduction



For system integrators, choosing the optimal storage solution can be a struggle. MLC products do not deliver the desired performance and longevity expected and the cost of SLC can far outweigh the benefits. iSLC is aimed at the segment between the high-end and mission-critical SLC market and the low-end MLC market.

iSLC technology is a flash solution that increases the performance, reliability and endurance of MLC NAND flash. The cells are enhanced through the screening and programming of SSD firmware, which enables the MLC NAND flash to mimic SLC.

This paper aims to explain the difference between these NAND flash technologies, and how iSLC is a solution that fits within the broader framework of the embedded and other high-end industries.

Background

As technology progresses, manufacturers are able to store more bits, and thus more information into each NAND flash cell. There are already devices holding three bits per cell (tri-level-cells, TLC,) and four bits per cell (quad-level cells, QLC) devices are in development. This trend will lead to a further decrease in cost and increase in capacity as the cells get stacked even more tightly together. However, the downside is a drastically lower number of program/erase (P/E) cycles, i.e. the number of times the storage drive can be fully written with data and then erased before eventually failing[1].

This is due to the one inherent issue that no SSD can escape: cell degradation. When the data in a cell is deleted, it is hit with a relatively powerful electric charge. This process will ever so slightly degrade the substrate of the cell. On this nanoscopic scale, these tiny impairments will accumulate and eventually lead to full device failure[2].

Another inherent issue is error bits. These occur when data transmitted encounters electrical or magnetic interference from the environment and one or more bits are flipped (1 to 0 or vice versa). As the bits per cell increase and the cell size tightens the risk for error bits also increases. Even though these error bits will be fixed by implemented error correcting code (ECC), they still impact performance. A lower error bit rate naturally means better performing SSD devices.

However, this is still great news for the average consumer as solid state devices become more affordable and the endurance is still more than enough for every-day use. Enterprise and industrial applications on the other hand, experience much higher P/E cycle numbers and have stricter performance requirements, which in turn can render MLC and other higher bits-per-cell technology unfit for use.

SLC vs MLC

The Struggle for Optimization

The primary difference between SLC and MLC is the number of bits stored in each NAND cell. SLC stores 1 bit of data per cell, while MLC stores 2 bits per NAND cell. This allows SLC to be more fault-tolerant than MLC, while supporting more write cycles per cell. SLC flash can provide longer endurance and is a perfect choice for high-end applications. Other key differences between SLC and MLC include read, write and erase times, P/E cycles, and handling of errors bits (see table 1).

Table 1. Comparing SLC and MLC

	Program Page	Erase Block	P/E Cycle	Bits corrected by ECC
SLC (24nm)	400μs	4ms	60K	24 bit/ 1024Bytes
MLC (15nm)	1400μs	5ms	3K	40 bit/ 1024Bytes

As indicated in this table, other than performing better in terms of speed, SLC also has a lower raw bit error rate (RBER). This is defined as the amount of bits that are wrongly written. For example: if the input sequence 01 01 01 01 is written as 01 11 11 01, two error bits have occurred. In terms of RBER, there is two error bits in a string of eight bits, giving a rate of 0.25 or 25%.

SLC NAND flash is more reliable and more enduring than MLC, and is the ideal solution for industrial and enterprise applications. However, due to its affordability, MLC flash is still a very functional choice, although at the expense of performance and endurance.

MLC's popularity is mainly driven by price. This has lead MLC NAND manufacturers to create larger capacity devices at a better cost efficiency ratio. The trade-off is a decrease in reliability and endurance, seen in figure 1. As NAND flash technology shrinks from 3Xnm down to 1Xnm, manufacturers require higher ECC capabilities to compensate for the decrease in reliability and endurance.

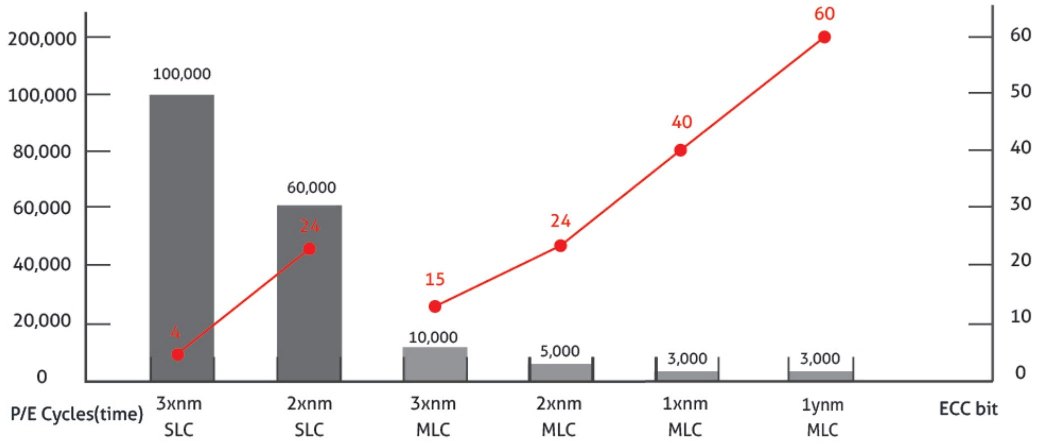
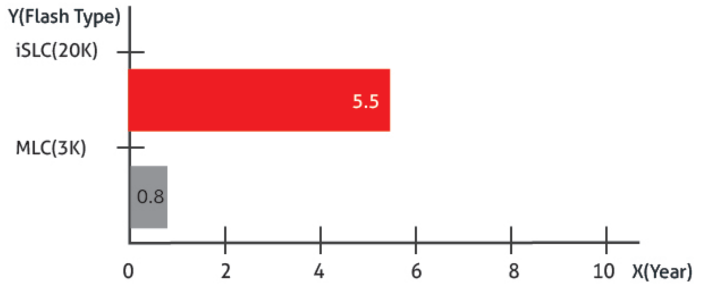


Figure 1 : MLC NAND Flash Trend

Many applications will fall in between these two flash types, where performance and endurance requirements exclude MLC alternatives. In this case, the system integrator is stuck with a more costly SLC option.

Cost-performance Optimization with iSLC

It is ideal to have iSLC performance mirror that of SLC flash, while the range in cost being close to MLC flash. An example to show the increase in endurance can be seen in figure 2. When writing 10 full disks of data per day with a 32GB SSD, the iSLC device lasts 5.5 years. This is a full seven times longer than MLC which does not reach a full year before failing.



Note: The above diagram is based on a test environment for a 100% sequential write.
Example: Write 32GB x 10 time/day=320GB/day

Figure 2: iSLC and MLC endurance comparison.

iSLC uses in-house designed firmware to force to the MLC flash to act as an SLC cell. Each SLC cell holds one bit - 1 or 0 -, while MLC holds two bits – 00, 01, 10 or 11. iSLC mimics SLC by only holding 1 bit in each NAND cell (see figure 3). This firmware tweak essentially allows the flash to perform close to that of SLC flash. This also increases endurance and data retention levels of the MLC NAND flash.

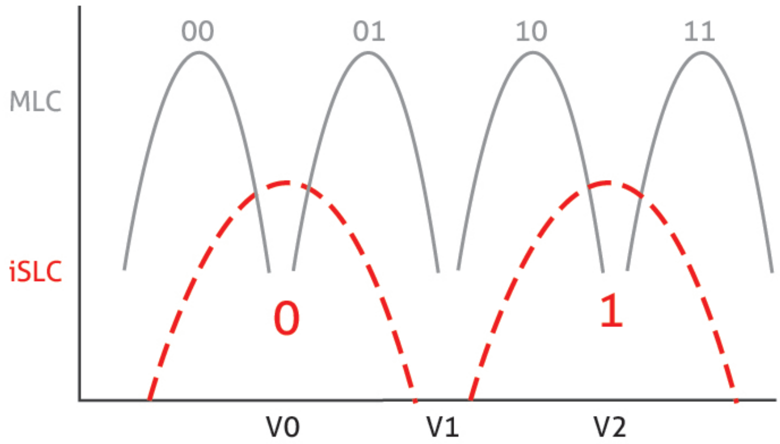


Figure 3: iSLC firmware technology

Testing Data

The average endurance in iSLC surpasses 20,000 P/E cycles, significantly increasing the lifespan of the drive compared to MLC flash. Table 2 illustrates a non-stop burn test with measured variables with both devices far surpassing the 20,000 limit; thus no errors occurred (data loss, data failure).

Table 2: Non-stop burn test with measured variables

Sample	Capacity	Page Size	Average Erase Count	Error	Total Data Written(GB)	Total Test Time (Hours)
1	16GB	16K	43,001	0	381,002.32	2,389.18
2	32GB	16K	29,021	0	868,884,25	4,298.54

Our tests show a lower amount of error bits for iSLC compared to MLC. When comparing the technology nodes of iSLC and MLC, 1xnm iSLC P/E cycle reached 20,000 times with error bits under 24 bits, while P/ E cycles for 1xnm MLC passed 3,000 with 40 error bits. Table 3 shows ECC bits comparison between iSLC and MLC.

Table 3: ECC bits Comparison between iSLC and MLC

Flash Type	Capacity	Average Erase Count	ECC
iSLC	16GB	34,733	15 bits
MLC	16GB	6,280	40 bits

Write performance for iSLC NAND flash is about 10% slower than SLC NAND flash, while MLC NAND flash is approximately 50% slower than SLC NAND flash. This is a significant jump in performance over typical MLC solutions. See Table 4.

Table 4: Comparing the Write performance for SLC, iSLC and MLC on SATA III			
Write (Max. MB/s)	1 CH	2 CH	4 CH
SLC	NA*	100	230
iSLC	50	100	230
MLC	20	40	140
*SLC starts with 2 channels.			

Conclusion

The advantages of iSLC can thus be summed up as:
- Extended lifespan and reliability compared to MLC
- Performance similar to SLC
- Price point around half that of SLC

iSLC strikes a good balance between affordability and performance. With the increased number of P/E cycles, product lifespan is boosted to seven times that of similar MLC devices, while performance reaches the levels of SLC Flash. These factors are all key in making iSLC the ideal storage solution for the high-end industrial and embedded market, where budget-friendly alternatives are more attractive.

Sources:
1.https://www.theverge.com/2017/6/28/15887902/toshiba-quadruple-level-3d-nand-cells-flash-memory
2.http://searchstorage.techtarget.com/podcast/How-NAND-flash-degrades-and-what-vendors-do-to-increase-SSD-endurance

The Innodisk Solution

Innodisk's 3IE4 Series includes the following			
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