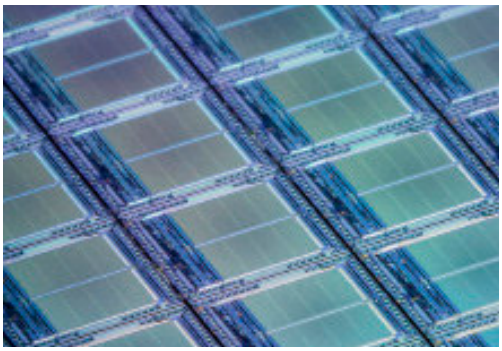
White Paper

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 3D triple-level cell (TLC) NAND flash. 3D TLC NAND flash cells are made to hold one bit per cell instead of three, effectively mimicking single-level cell (SLC) NAND flash.

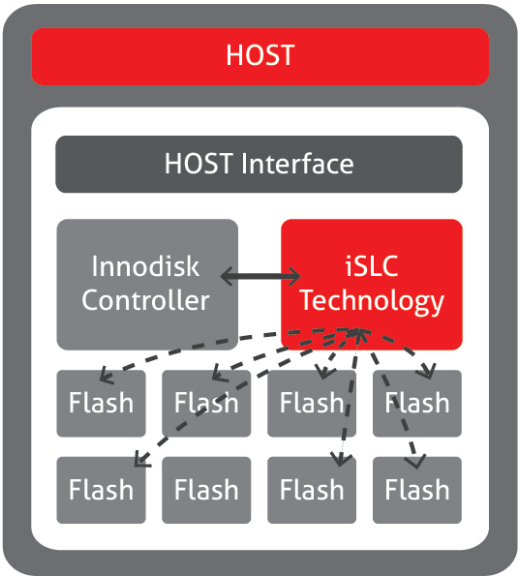
iSLC is a hybrid between 3D TLC and SLC technology, where performance is closer to SLC and endurance is significantly higher than 3D TLC. The price roughly falls between 3D TLC and SLC products.

The program/erase (P/E) cycle limit for iSLC is around 30,000, while 3D TLC 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 3D TLC device showed a significant difference in the number of error checking and correction (ECC) bits (iSLC 60, 3D TLC 120). Write performance tests indicate that iSLC of 3D TLC is the same level with SLC

Introduction

For system integrators, choosing the optimal storage solution can be a struggle. 3D TLC 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 3D TLC market.



iSLC technology is a flash solution that increases the performance, reliability and endurance of 3D TLC NAND flash. The cells are enhanced through the screening and programming of SSD firmware, which enables the 3D TLC 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 3D TLC and other higher bits-per-cell technology unfit for use.

SLC vs 3D TLC

The Struggle for Optimization

The primary difference between SLC and 3D TLC is the number of bits stored in each NAND cell. SLC stores 1 bit of data per cell, while 3D TLC stores 3 bits per NAND cell. This allows SLC to be more fault-tolerant than 3D TLC, 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 3D TLC include read, write and erase times, P/E cycles, and handling of errors bits (see table 1).

Table 1. Comparing SLC and 3D TLC

	Program Page	Erase Block	P/E Cycle	Bits corrected by ECC
SLC (24nm)	400μs	4ms	60K	24 bit/ 1024Bytes
3D TLC	2300μs	10ms	3K	120 bit/1024KBytes

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 number 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 are 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 3D TLC, and is the ideal solution for industrial and enterprise applications. However, due to its affordability, 3D TLC flash is still a very functional choice, although at the expense of performance and endurance.

3D TLC's popularity is mainly driven by price. This has lead 3D TLC 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 improves from 32 layers to 128 layers, manufacturers require higher ECC capabilities to compensate for the decrease in reliability and endurance.

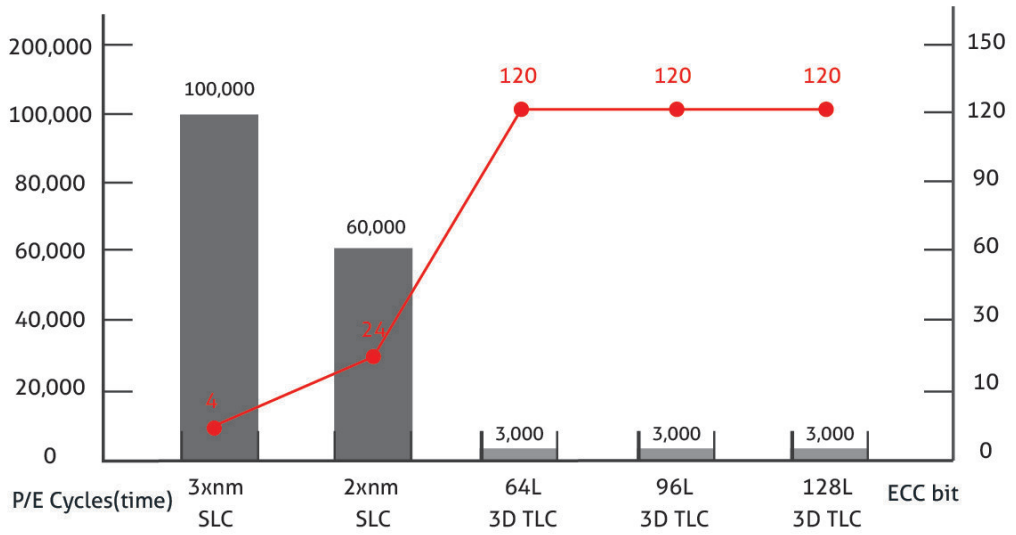
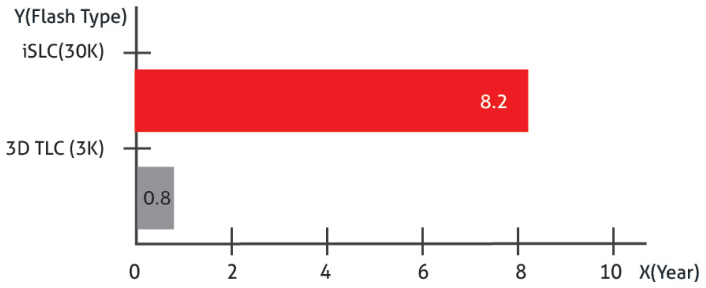


Figure 1: NAND Flash Trend

Many applications will fall in between these two flash types, where performance and endurance requirements exclude 3D TLC 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 3D TLC 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 8.2 years. This is a full seven times longer than 3D TLC 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 3D TLC endurance comparison.

iSLC uses in-house designed firmware to force to the 3D TLC flash to act as an SLC cell. Each SLC cell holds one bit - 1 or 0 -, while 3D TLC holds three bits – 000, 001, 010, 011, 100, 101, 110, 111. 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 3D TLC NAND flash.

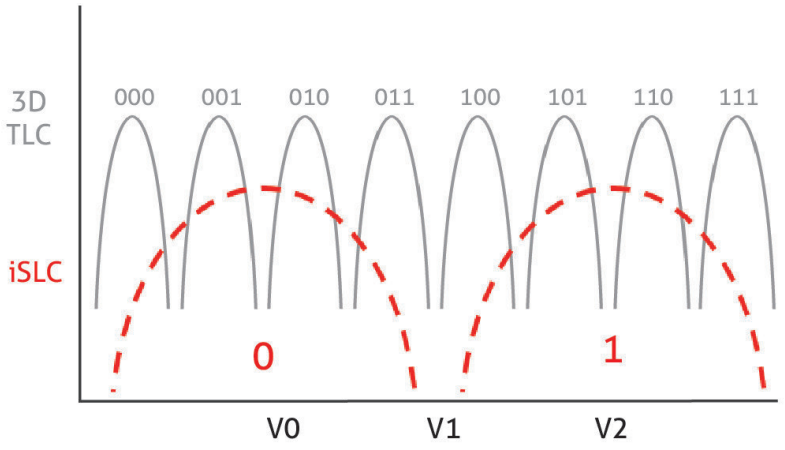


Figure 3: iSLC firmware technology

Testing Data

The average endurance in iSLC surpasses 30,000 P/E cycles, significantly increasing the lifespan of the drive compared to 3D TLC flash.

Our tests show a lower amount of error bits for iSLC compared to 3D TLC. When comparing the technology nodes of iSLC and 3D TLC, 64L iSLC P/E cycle reached 30,000 times with error bits under 60 bits, while P/ E cycles for 3D TLC passed 3,000 with 120 error bits. Table 2 shows ECC bits comparison between iSLC and 3D TLC.

Table 2: ECC bits Comparison between iSLC and 3D TLC

Flash Type	Capacity	Average Erase Count	ECC
iSLC	64GB	55,000	60 bits
3D TLC	64GB	3,200	120 bits

Write performance for iSLC NAND flash is about 60% faster than SLC NAND flash, while 3D TLC NAND flash is approximately 50% slower than SLC NAND flash. This is a significant jump in performance over typical 3D TLC solutions. See Table 3.

Table 3: Comparing the Write Performance for SLC, iSLC and 3D TLC on SATAIII

Write (Max. MB/s)	1 CH	2 CH	4 CH
SLC	NA*	100	230
iSLC	NA*	190	380
3D TLC	35	70	150

* SLC & iSLC starts with 2 channels

Conclusion

The advantages of iSLC can thus be summed up as:
- Extended lifespan and reliability compared to 3D TLC
- 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 ten times that of similar 3D TLC devices, while performance reaches the levels of SLC Flash. These factors are all key to making iSLC the ideal storage solution for the high-end industrial and embedded market, where budget-friendly alternatives are more attractive.

Sources:
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2.http://searchstorage.techtarget.com/podcast/How-NAND-flash-degrades-and-what-vendors-do-to-increase-SSD-endurance

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