nCACHE™ 4.0 WRITE CACHE: BRIDGING SPEED, CAPACITY AND RELIABILITY

Introduction

The SANDISK® nCache™ 4.0 Technology is our proprietary SLC[1] write caching technology which improves performance for consumer applications and workloads such as when multitasking and copying large files or folders. This Technology Brief explores the implementation and benefits of the SANDISK® nCache™ 4.0 Technology.

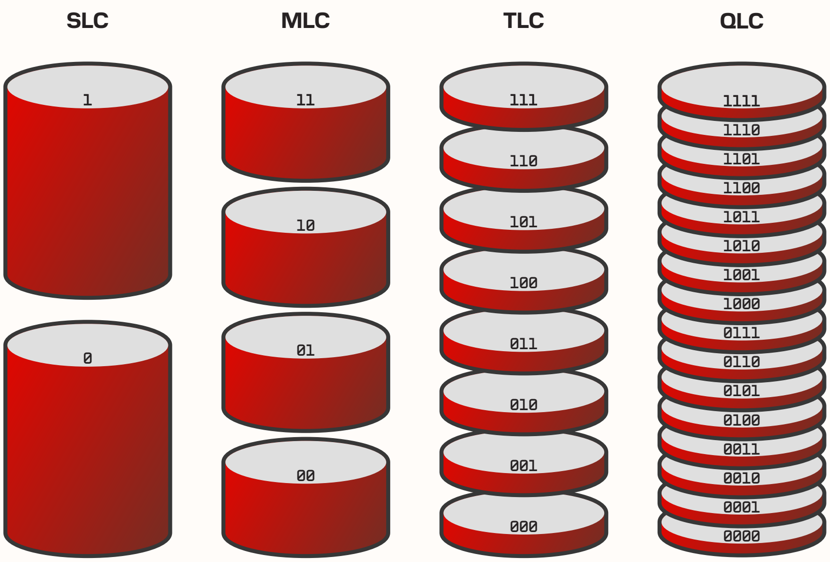
Background

NAND flash memory is a non-volatile storage that retains data without power and is ubiquitous in consumer storage devices such as USB thumb-drives, portable SSDs, and internal SSDs. The basic building block is the memory cell, which stores bits as electrical charges. In a single-level cell (SLC[1]), a 1 represents no charge (no data, default) and 0 represents a charge (or data present). NAND flash memory has evolved to keep up with the trend for higher capacity SSDs and can store multiple bits per cell. As seen in Figure 1, MLC (Multi-Level Cell - 2 bits/cell), TLC (Tri-Level Cell - 3 bits/cell), and QLC (Quad-Level Cell 4 bits/cell) are the NAND types deployed in today's SSDs.

Memory cells are organized into pages (for reading/programming) and blocks (for erasing). Blocks can consist of 512 pages or more. While data can be read and written (programmed) by pages, memory cells must first be erased by blocks before writing data to the memory cell, consequently, causing writes to be slower than when reading data.

Each memory cell has a limited number of program/erase (P/E) cycles in its lifespan. This P/E limit is a factor of the type of NAND (SLC, MLC, TLC, QLC) and typically decreases as the number of bits per cell increases. This necessitates 'wear leveling' by optimizing write procedures in the SSD. Further, while these cells offer increased memory densities, they require more precise programming to distinguish between the multiple charge states, consequently slowing down writes to NAND. This creates a need for a balance between speed and capacity, and that's where our nCache 4.0 Technology comes in.

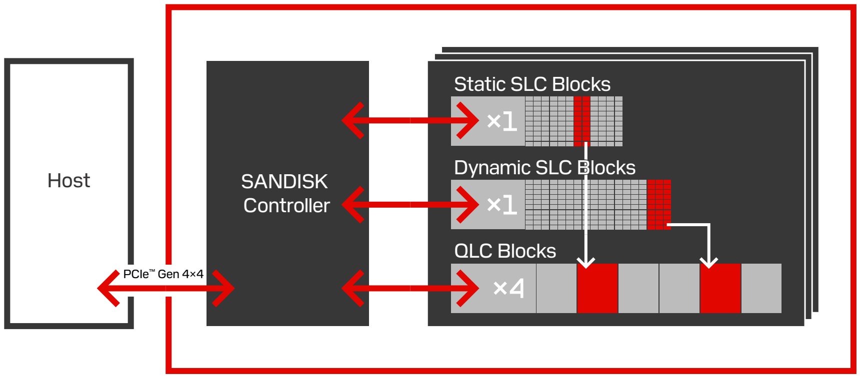
Figure 1



SANDISK® nCache™ 4.0 Technology: Speed Meets Capacity

To provide both high performance and high endurance, modern Sandisk consumer SSDs integrate the nCache 4.0 technology, which is a high-speed hybrid SLC[3] write cache where data is written first before moving to the user space which is typically a denser NAND. Then, during idle times, data is written to user space to free up the cache for subsequent writes in a process known as **Folding.**[4] nCache 4.0 technology features a hybrid design, which is a combination of fixed SLC blocks, which is a percentage of the SSD's capacity, as well as a dynamic SLC blocks which is a percentage of the unallocated user space (Figure 2).

Figure 2



Hybrid SLCs were a watershed moment in Flash memory. Given that Burst and Sustained Write performance is directly related to the size of the SLC pool, the ability to convert MLC to SLC and back made SSDs perform faster for longer.

The primary function of nCache 4.0 are twofold:

1. When applications write data to the SSD, data is first written to the write cache. This data is then moved into slower user space during idle times. As a result, consumers will experience fast system responsiveness, smooth application multitasking, and blistering faster file copies.
2. Since multi-level cells have decreasing number of P/E cycles resulting lower write endurance, nCache 4.0 technology mitigates wear by absorbing writes into higher endurance SLC blocks and by organizing data before writing to lower endurance multi-level cells which also reduces the **Write Amplification Factor (WAF).**[5]

Consumer Benefits

nCache 4.0 technology improves the PC's overall performance when running common consumer applications and improves the lifespan of Sandisk consumer SSDs. Here are a few examples of consumer benefits:

Better OS Responsiveness

The PC's Operating System (OS) has hundreds of tasks which write data to the SSD. nCache 4.0's hybrid SLC write cache can make your PC more responsive by helping reduce system lags, which are all too common.

Better Application Responsiveness

Many feature rich applications such as video editors and productivity suites typically write large amounts of metadata to the SSD and automatically saves your work in the background. When there are multiple applications in use, this could lead to a slow down. nCache 4.0 helps mitigates this with its hybrid SLC write cache, vastly improving consumer multitasking experience.

Faster Large File Copies

Content creators typically have large media libraries consisting of large files and folders. Moving or copying these large files could take a long time, adding idle time to the creator's workflow. nCache 4.0 maintains top write speed thanks to the dynamic SLC write cache available, making workflows more efficient.

Helps Optimize User Space

Consumers want to know their stored data is protected on the SSD. nCache 4.0 is a non-volatile fast write cache quickly storing the user data first, and then safely writing it to lower endurance user space in a NAND friendly way to help prevent unnecessary wear and tear preventing early drive wearout.

Sandisk SSDs

All of our most popular consumer SSDs, such as the award winning WD_BLACK SN8100 NVMe™ SSD, WD_BLACK SN850X NVMe™ SSD, WD_BLACK SN7100 NVMe™ SSD, and the WD Blue® SN5100 NVMe SSD are equipped with the SANDISK® nCache 4.0 Technology.

With nCache 4.0, our SSDs are ideal for consumers seeking a storage upgrade to their PC giving a spark in performance whether for faster boots, quicker multitasking, or making the PC more responsiveness for everyday tasks.

Conclusion

nCache 4.0 technology uses a hybrid SLC write cache design which is a significant advancement in SLC write caching, bringing high performance and reliability to high capacity SSD. This technical innovation improves the PC experience for consumer storage while simultaneously ensuring SSD lifespan. nCache 4.0 technology gives credence to Sandisk's ethos of leading the market with true innovation and continuous improvement.

Definitions

1. **SLC (Single-Level Cell):** NAND flash memory that stores one bit per cell using two voltage states (charged/uncharged), offering high performance but at higher cost per gigabyte.
2. **MLC (Multi-Level Cell):** NAND flash memory that stores two bits per cell using additional voltage threshold levels, providing higher storage density and lower cost.
3. **Hybrid SLC Cache:** A write caching architecture that combines both static and dynamic SLC pools to optimize host write performance. The static component provides consistent cache availability, while the dynamic component offers variable capacity that decreases as user data fills the drive, maximizing cache size when storage utilization is low.
4. **Folding:** The process of migrating data from SLC cache to the drive's native multi-level cell (MLC/TLC/QLC) storage. This background operation occurs when the SLC cache reaches capacity or during idle periods, converting temporarily cached single-level data back to its intended multi-level format to free cache space for new writes.
5. **Write Amplification Factor (WAF):** A metric measuring the ratio of actual NAND writes to host-requested writes, expressed as a multiplier (e.g., 3x). Lower WAF values indicate more efficient operations, while higher values suggest increased NAND wear.

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