

Innovations in Non-Volatile Memory

3D NAND and its Implications

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Leading with New Innovations: 3D NAND

How 3D NAND Enables Innovation:

3D NAND solutions bring significant performance, power, and capacity advantages to storage applications, especially archive

Pack in More Capacity – Density Counts

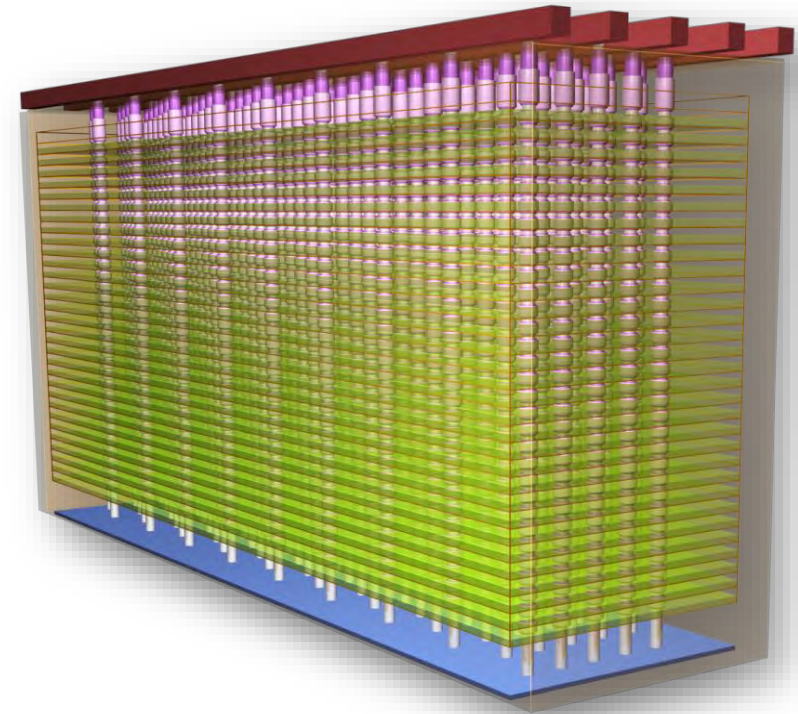
Get 3 times the capacity of existing NAND products—enough to enable 3.5TB gum stick-sized SSDs or more than 10TB in standard 2.5-inch SSDs. In the future, 3D NAND will enable 30-60 TB in the standard 2.5” 15mm form factor.

Boost Performance – Deposit/Recall Items from Archive

Achieve significantly higher read/write bandwidth and I/O speeds, as well as improved random read performance, thanks to 3D NAND’s fast 4K read mode.

Save Power & Cooling

Reduce power consumption significantly in standby mode thanks to 3D NAND’s new sleep mode features that cut power to inactive NAND die (even when other die in the same package are active).



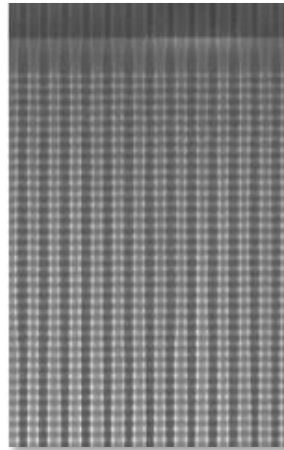
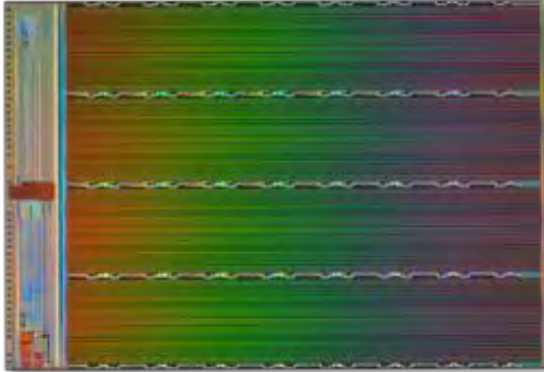
How did we do it?

Use floating gate cell technology in 3D NAND—a proven cell technology that enables better performance, quality, and reliability. Stack 32 storage tiers to achieve the highest-capacity NAND die available today: 256Gb multilevel cell (MLC) and 384Gb triple-level cell (TLC) 3D NAND.

Progression of 32GB of MLC NAND flash



3D NAND Comparison with Planar NAND Scaling

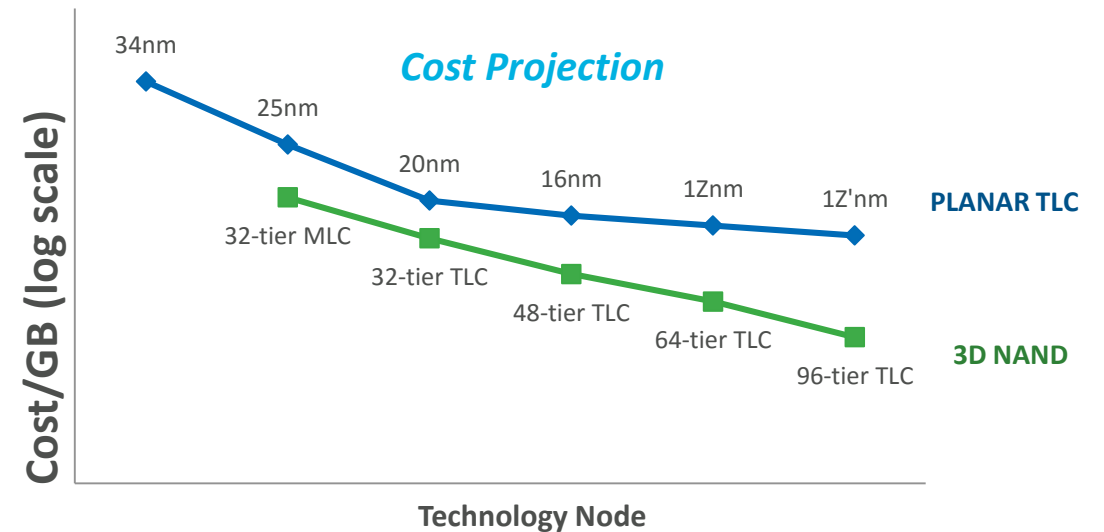
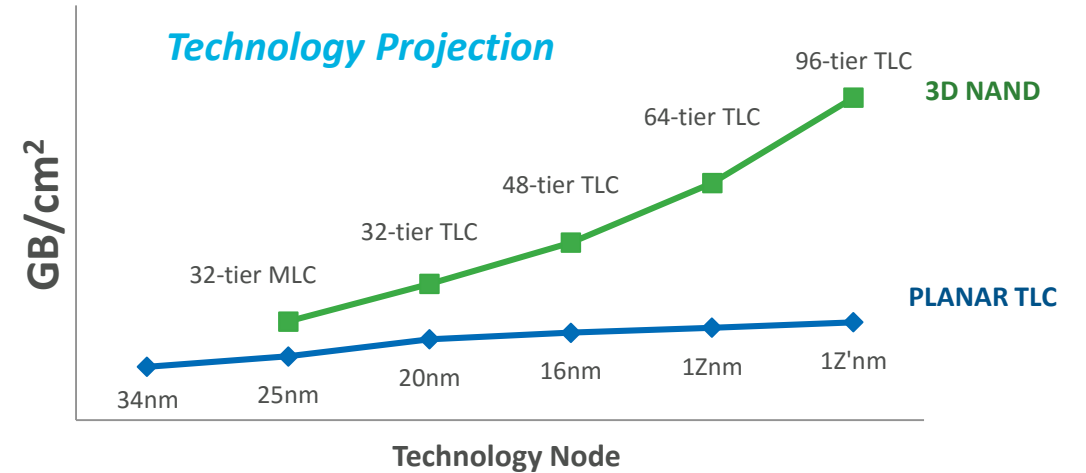


Planar NAND scaling

- Planar can be scaled below 16nm, but performance and cost are not competitive with 3D NAND
- Industry emphasizing 3D NAND advantages

3D NAND scaling

- 3D NAND cost improvement over planar expands with subsequent nodes
- 3D NAND cell architecture enables significant performance improvement relative to planar technology
- Today's single-die (~1 cm²) density is 384Gb/cm²
- Near future single-die density planned for 1Tb/cm²



Driving All Flash Storage Adoption

Superior SSD Capacities & Compelling TCO

Compelling 4 Yr TCO SSD vs. HDD

- \$/GB tipping point in 2016 with SSD capacity 2.3x HDD capacity, growing to 3.4x by 2018
- TCO benefit of SSDs will drive rapid adoption of the much-solid state data center over next 4-5 years
 - Lower power/cooling footprint
 - Higher reliability
 - AFR < 0.1%
 - Greater density



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Source: TCO Analysis, Wikibon 2015

	2015	2016	2017	2018
Highest Available Capacity HDD	10TB	11TB	12TB	12.5TB
Highest Available Capacity SSD	8TB	25.6TB	33TB	43TB
SSD Capacity / HDD Capacity	0.8x	2.3x	2.75x	3.4x

Source: Gartner 2015

Near-Future SSD Target Platform for QLC Media

Very High Capacity Intelligent Drive

- < \$100/TB for acquisition of finished product @ typical street discounts
- PCIe Gen 3/4, 64TB+ , 2.5"-15mm form factor, U.2 interface (NVMe), 3.072PB raw in 2U
 - Other form factors possible – modules, 3.5" (120 TB+), etc.
- Performance priorities: Seq Read, Seq Write (10-30W @ 5W steps), Read IOPs
- Performance: x4 saturation on reads (3.2 GB/s); 1-3 GB/s writes based on power
- Workload: 90%/10% Read/Write +/- 5%
 - Writes are @ 32K-4MB IO sizes, smaller host access routed to NVM buffer/namespaces
 - Reads are 4K-4MB IO sizes
- Platform: 2U-48 2.5"-15mm, NVMe, PCI-Gen3x4 each
- Endurance: 500 sequential fills over life (32 PB TBW)
- Shelf Retention: 3 months @ 40C, 12 months @ 25C
- Low Power/Idle Mode (<0.7W) and Fast TTR capability
- 200 Gb/s (20 GB/s) throughput currently (8x25)
- Enterprise Data Integrity
 - Drive-level RAIN, host-level EC, cluster-wide EC (e.g. Ceph)



