Zoned Storage for the Zettabyte Age

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Silicon Technology & Manufacturing

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August 6, 2019

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Tour De Flash: Back to Climbing

NAND Flash Industry Revenue ($ Billion)

Have we Reached a Cyclical Trough?

Source: "NAND Quarterly Insights Q2/19," Forward Insights, May 2019
Zooming into the Zetta-Zone

~32ZB
Data Created in 2018

~103ZB
Data Created in 2023

Source: IDC Global DataSphere Forecast, 2019-2023: Consumer Dependence on the Enterprise Widening, January 2019, DOC #US44615319
Cloudy with a Chance of More Data

By 2023, >90% of data created will be generated by machines

Source: Applied Materials, SEMICON West, AI Design Forum, July 2019
‘There’s Gold in Them Thar’ Bits

Data Created

<table>
<thead>
<tr>
<th>Year</th>
<th>Data</th>
<th>Core</th>
<th>Edge</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>2018</td>
<td>32ZB</td>
<td>13%</td>
<td>24%</td>
<td>63%</td>
</tr>
<tr>
<td>2023</td>
<td>103ZB</td>
<td>17%</td>
<td>26%</td>
<td>57%</td>
</tr>
</tbody>
</table>

Data Stored

<table>
<thead>
<tr>
<th>Year</th>
<th>Data</th>
<th>Core</th>
<th>Edge</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>2018</td>
<td>5ZB</td>
<td>33%</td>
<td>62%</td>
<td>95%</td>
</tr>
<tr>
<td>2023</td>
<td>12ZB</td>
<td>8%</td>
<td>57%</td>
<td>65%</td>
</tr>
</tbody>
</table>

Sources: 1) IDC Global DataSphere Forecast, 2019-2023: Consumer Dependence on the Enterprise Widening, January 2019, DOC #US44615319; 2) IDC, Worldwide Global StorageSphere Installed Base Forecast, 2019-2023: The Global StorageSphere Installed Base by Core, Edge, and Endpoint, April, 2019, DOC #US45009319; Percentages and numbers approximate, rounded off to whole number.
Storage Darwinism

Annual Exabytes Shipments

- Data Center SSD: 44% CAGR
- Capacity Enterprise HDD: 34% CAGR
- Other: 11% CAGR

Don’t Scale, Don’t Survive!

Source: Western Digital
Gordon Moore meets IM Pei

3D NAND: Scaling in the Z-Direction

24-Layer (BiCS1) 2014 (ES)
48-Layer (BiCS2) CY2016 (MP)
64-Layer (BiCS3) CY2017 (MP)
96-Layer (BiCS4) CY2018 (MP)
1XX-Layer CY2020 (MP)
Capital Intensity of Industry 3D NAND Generations

Capital Intensity
(Capex $M / 1% bit growth)

Sources: Western Digital Estimates; Salesforce Tower cost per sq. ft., https://en.wikipedia.org/wiki/Salesforce_Tower
Honey, I Shrunk the Memory Holes

Memory Hole Density (MH/mm²)

48L  64L  96L  1XXL  1YYL

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Scaling gets Vertigo

Cell Density (MH/mm²)xN

Memory Hole Density (MH/mm²)

N = 48L  64L  96L  1XXL  1YYL

vertical
lateral

x

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Three’s Company

logical

X

vertical

z

X

y

x

lateral

TLC Bit Density

$$((MH/mm^2)\times N\times B)$$

Cell Density

$$((MH/mm^2)\times N)$$

Memory Hole Density

$$(MH/mm^2)$$

N = 48L 64L 96L 1XXL 1YYL
It is all Quite Logical: 4 Bits Per Cell

Single memory cell

16 Data Levels Per Cell

SSD based on 1.33Tb X4 (QLC)
# QLC: The New Logical Scaling Frontier

<table>
<thead>
<tr>
<th></th>
<th>64L</th>
<th>96L</th>
</tr>
</thead>
<tbody>
<tr>
<td>MH Density</td>
<td>1x</td>
<td>1.1x</td>
</tr>
<tr>
<td>Cell Density</td>
<td>64x</td>
<td>106x</td>
</tr>
<tr>
<td>TLC Bit Density</td>
<td>192x</td>
<td>317x</td>
</tr>
<tr>
<td>QLC Bit Density</td>
<td>256x</td>
<td>422x</td>
</tr>
</tbody>
</table>

**QLC Bit Density**

\[(\text{MH/mm}^2) \times N \times B\]

**TLC Bit Density**

\[(\text{MH/mm}^2) \times N \times B\]

**Cell Density**

\[(\text{MH/mm}^2) \times N\]

**MH Density**

\[(\text{MH/mm}^2)\]
### Too Much of a Good Thing

<table>
<thead>
<tr>
<th>Scaling Benefit</th>
<th>2 bits per cell</th>
<th>3 bits per cell</th>
<th>4 bits per cell</th>
<th>5 bits per cell</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SLC → MLC</strong></td>
<td>100%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>MLC → TLC</strong></td>
<td>50%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>TLC → QLC</strong></td>
<td>33%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>QLC → PLC</strong></td>
<td>25%</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **ER**: Error Rate
Fantastic 4: The Rise of QLC

Assuming same adoption rate as MLC→TLC

Sources: 1) Western Digital Data. 2) Forward Insights, NAND Quarterly Insights Q2/19, May 2019

Bit Shipment Mix Percentage

Enterprise

Client

Mobile

3D-QLC

3D-TLC

~50% QLC bits by CY2025

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'Something’s Gotta Give’

- Per Die Write Bandwidth (MB/s)
- Page Size (kB)
- MLC
- TLC
- QLC

Design Parameters:
- Number of Planes
- Die Size
- Power
- Page Size
- # of Bits per Cell
## The Data Storage Approach for the Zettabyte Age

### Is There a Problem?

<table>
<thead>
<tr>
<th>Feature</th>
<th>QLC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enables scaling</td>
<td>✓</td>
</tr>
<tr>
<td>Cost/TCO benefit</td>
<td>✓</td>
</tr>
<tr>
<td>Great access/read performance</td>
<td>✓</td>
</tr>
<tr>
<td>Write limitations</td>
<td>☒</td>
</tr>
</tbody>
</table>
### We Have Seen This Movie Before

<table>
<thead>
<tr>
<th>Feature</th>
<th>ZNS QLC</th>
<th>SMR HDD</th>
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<tr>
<td>Enables scaling</td>
<td>![Checkmark]</td>
<td>![Checkmark]</td>
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<td>![Checkmark]</td>
<td>![Checkmark]</td>
</tr>
<tr>
<td>Write limitations</td>
<td>![X]</td>
<td>![X]</td>
</tr>
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**What is SMR?**

Shingled Magnetic Recording (SMR) and HDD scaling

- Scale physically by adding disks, enlarging disks, and narrowing tracks
- Scales “logically” by shingling more tracks per zone
- SMR ecosystem enables access to highest capacities

* Source: Western Digital internal modeling data, February /April 2019
Evolution of the Existing Data Center

Data growth powers the need for purpose-built solutions

Incoming Data & Workloads ➔ Compute ➔ Pass-through Data Transfer ➔ Traditional Storage

General Purpose Compute

- FPGA
- GPU
- TPU

HDDs

NVMe SSDs

Storage architectures must become purpose-built
Zoned Storage
Data-Centric Architecture for the Zettabyte Age
Re-architecting for the Zettabyte Age

Zoned storage enables efficiency and intelligent data placement

Incoming Data & Workloads ➞ Data Intelligence & Collaboration Layer ➞ Software Defined Storage ➞ Zoned Storage

Leverage investment through purpose-built Zoned Storage

- High Capacity SMR HDDs
- ZNS QLC SSDs

File-System with SMR Support (f2fs, btrfs)

Block Layer

SCSI/ATA NVMe

LINUX KERNEL

USER SPACE

libzbc
Zoned Namespaces Enables Intelligent, Lean SSDs

ZNS provides host with system-level intelligence for data placement.

Up to 8x \textit{DRAM reduction}

Up to 10x \textit{Overprovision reduction}

Source: Western Digital internal modeling data, 2019
Zoned Namespaces Enables Intelligent, Lean SSDs

ZNS provides host with system-level intelligence for data placement

Every virtual machine can be assigned a zone
# Zoned Storage Enables Zettabyte Scale

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<td>✔️</td>
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</tr>
<tr>
<td>Write limitations management</td>
<td>✗</td>
<td>✗</td>
</tr>
<tr>
<td>Data orchestration with enhanced control</td>
<td>✔️</td>
<td>✔️</td>
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</table>
The Power of Data at Zettabyte Scale

Zoned Storage enables tomorrow’s data needs

Sensor Data Analysis

- IoT
- Telemetry Data
- Massive Data Sets
- Video
- Analytics

Artificial Intelligence/
Machine Learning

- Data Preparation
- Ingest
- Archive Data
- Deployment/Inference
- Training Cluster

Server-less

- Function as a Service (FaaS)
- Event driven compute
- Tenant over subscription

Unified approach to manage naturally serialized data at scale

Enables predictable performance
Leading the Way with Zoned Storage

ZNS NVMe SSD Platform
Leading the Way with Zoned Storage

New Purpose-built NVMe SSDs
Leading the Way with Zoned Storage

ZNS NVMe SSD Platform

New Purpose-built NVMe SSDs

SMR HDD Platform
Leading the Way with Zoned Storage

ZonedStorage.io

Zoned Storage is a class of storage devices that enables host and storage devices to cooperate to achieve higher storage capacities, increased throughput, and lower latencies. The zoned storage interface is available through the SCSI Zoned Block Commands (ZBC) and Zoned Device ATA Command Set (ZAC) standards on Shingled Magnetic Recording (SMR) hard disks today and is also being adopted for NVMe Solid State Disks with the upcoming NVMe Zoned Namespaces (ZNS) standard.

Learn more about Zoned Storage Devices »  Learn more about Linux® Software Support »

QUICK START GUIDE

Learn how to setup a Linux system supporting zoned block devices and start experimenting with physical and emulated zoned storage devices.

Get Started »
Leading the Way with Zoned Storage

ZNS NVMe SSD Platform

New Purpose-built NVMe SSDs

SMR HDD Platform

Zoned Storage is a new class of storage devices that enables host and storage devices to cooperate in a way that maximizes performance, reliability, and resource utilization. The Zoned Storage platform is available through the ZNS (Zoned Namespace) and Zoned Device interfaces. ZNS is designed to provide unified namespace management and data protection for both NVMe and traditional storage devices.
Zoned Storage

**SMR** Built and supported via open source

**ZNS** Extends Flash Scaling & QLC for the Data Center

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**Innovation Through Intelligent Data Placement**

**TCO** Improves TCO

**Increases Data Storage**

**Based on Industry Standards**

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