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Flash Memory Basics for SSD Users

April 2014, Rainer W. Kaese



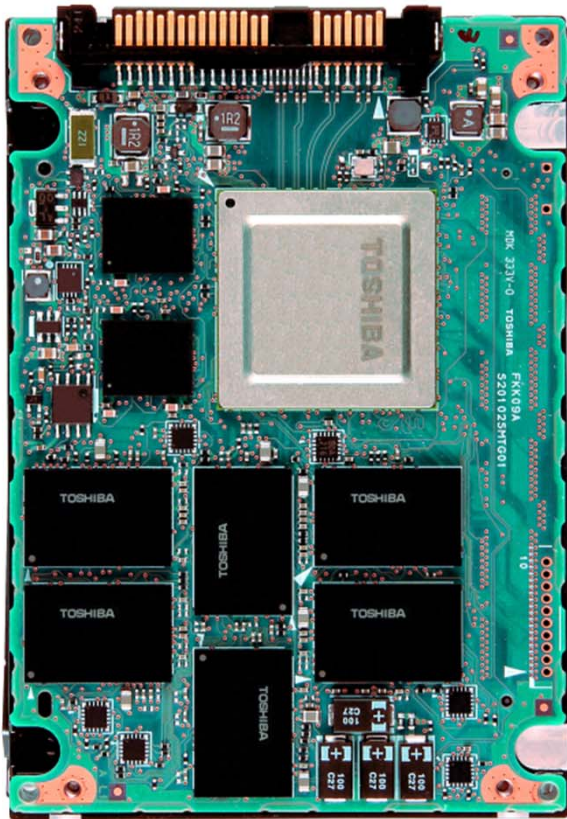
Toshiba Electronics Europe
Storage Products Division

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SSD vs. HDD

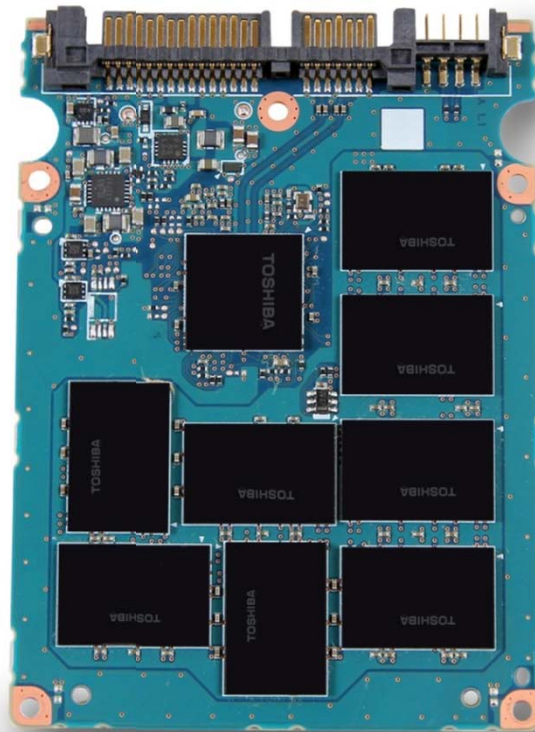
Enterprise SSD

Can write the full capacity **30x** per day over lifetime



Client/Laptop SSD

Can write the full capacity **0.1x** per day over lifetime



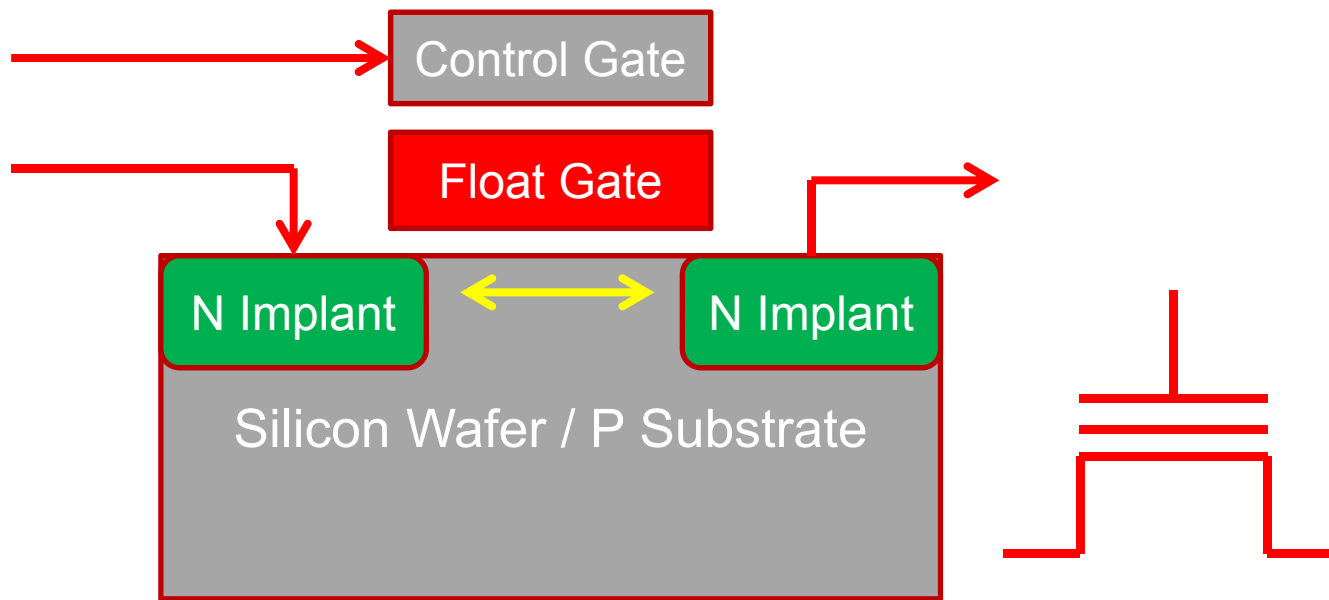
HDD

No write limitation



Flash Memory Technology („Simplified“)

Flash memory was invented by Dr. [Fujio Masuoka](#) while working for [Toshiba](#) circa 1980. According to Toshiba, the name "flash" was suggested by Masuoka's colleague, [Shōji Ariizumi](#), because the erasure process of the memory contents reminded him of the [flash of a camera](#) (source: Wikipedia)

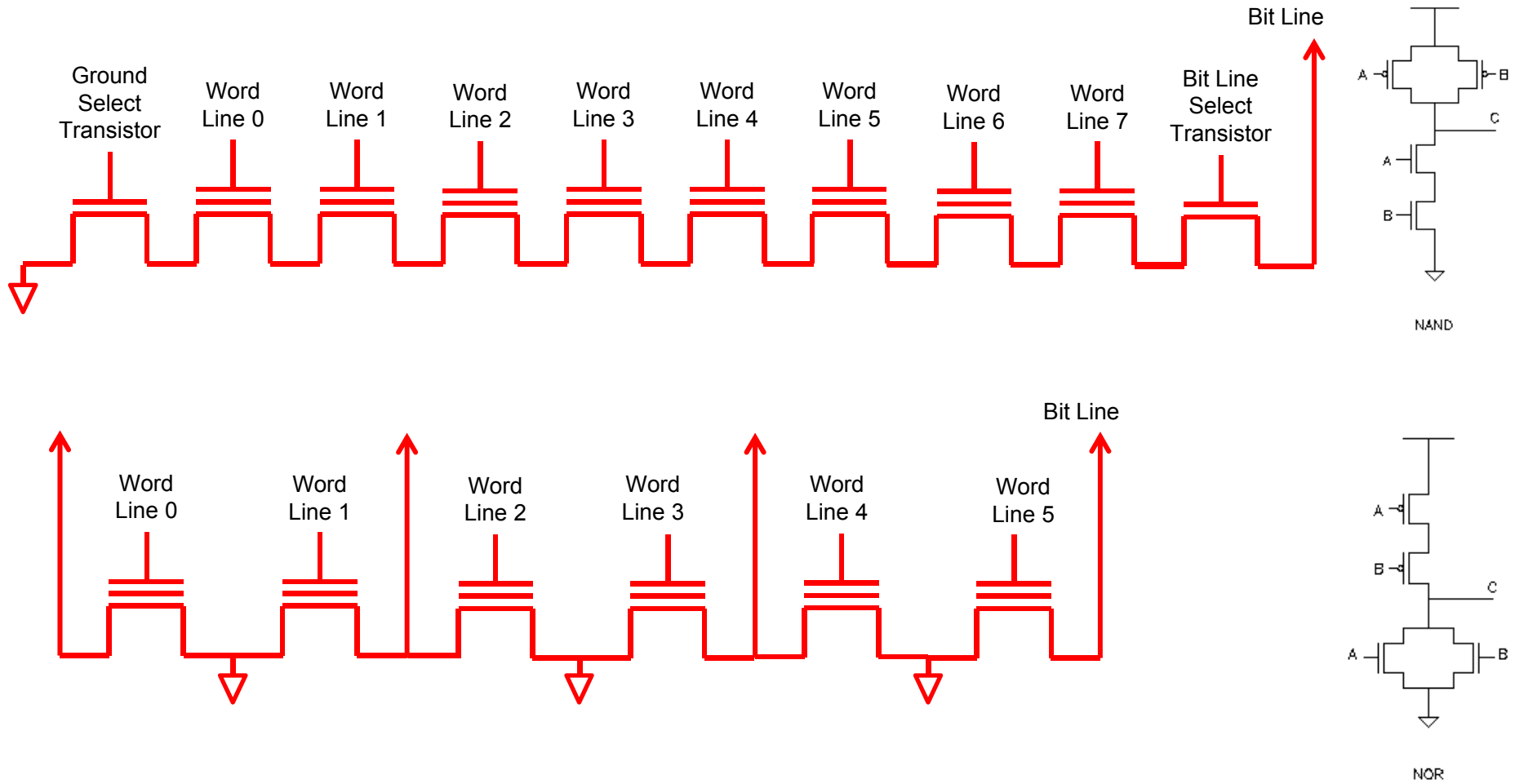


Structure (Cross-Section) of Flash Memory Bit Cell

Symbol



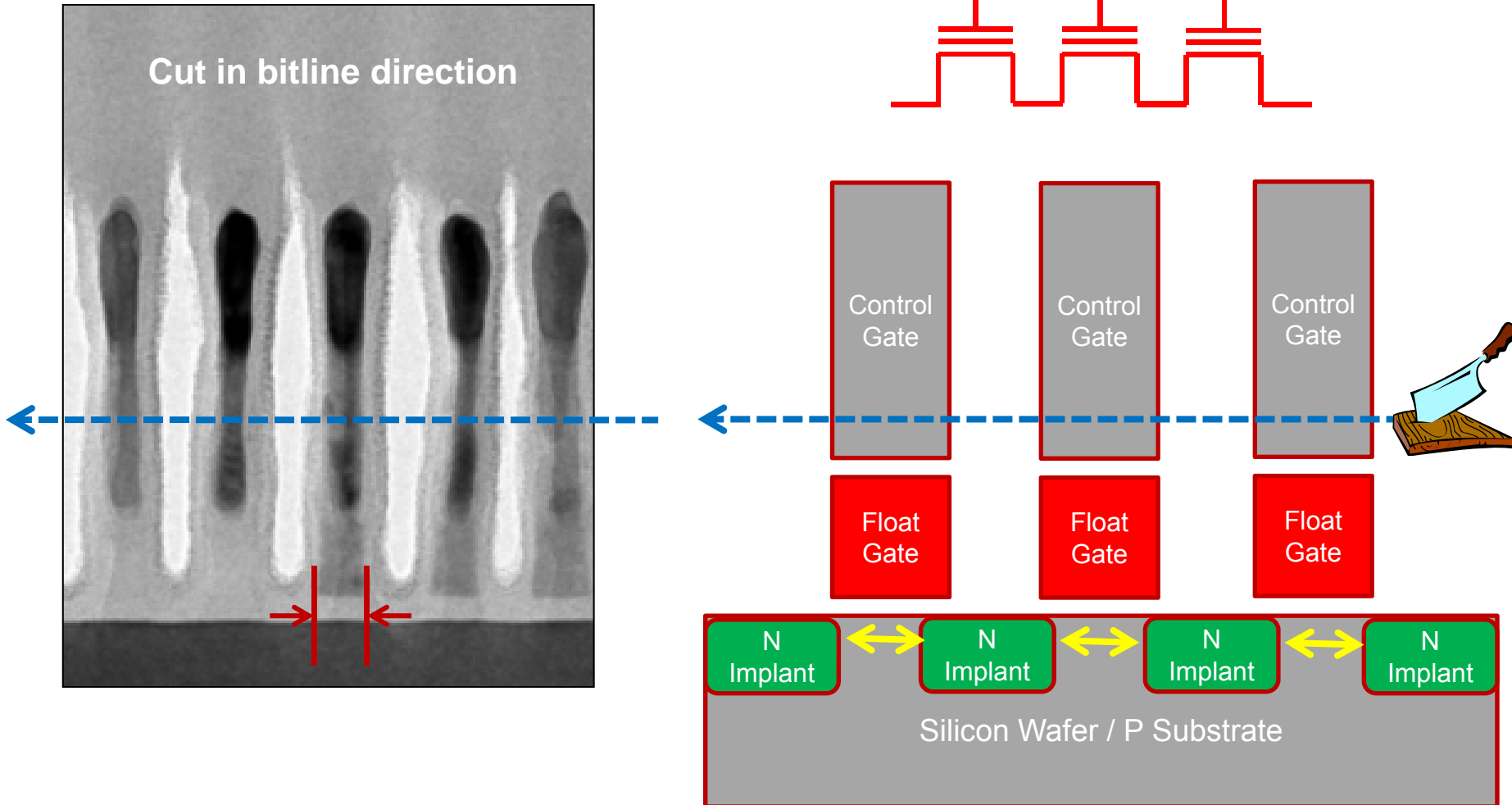
NAND Flash vs. NOR Flash



(NAND-) Flash Memory Cell Cross Section

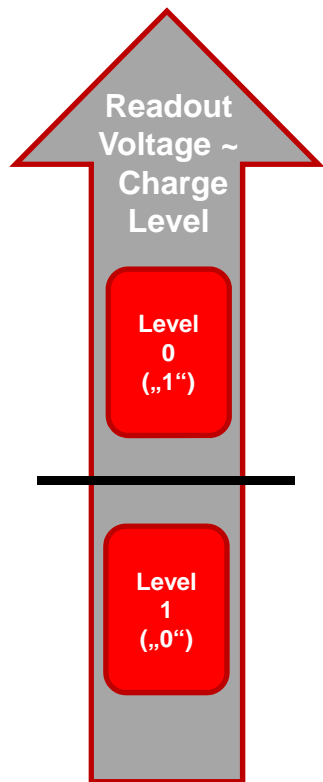
19nm

Cut in bitline direction



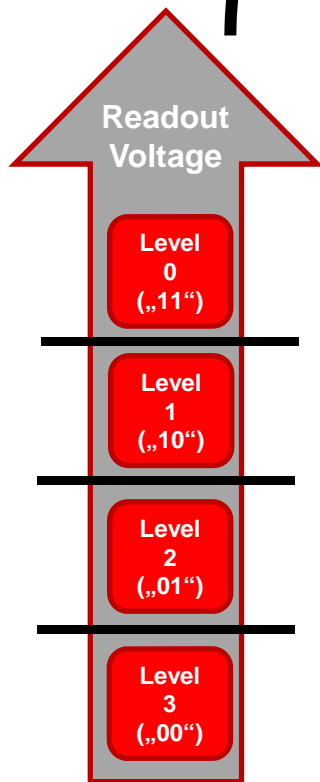
SLC, MLC, eMLC, pSLC and TLC

SLC
(Single Level Cell)
 (1 or 0)

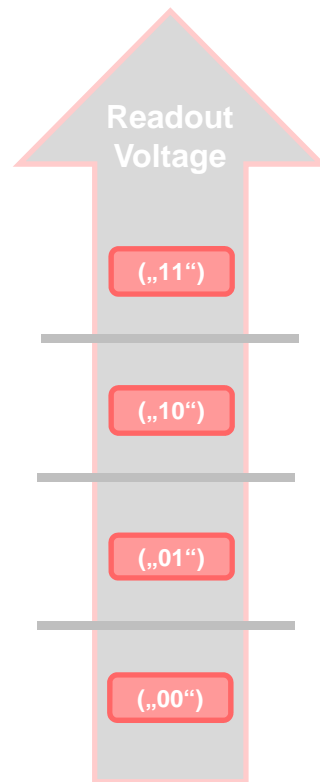


SLC

MLC
(Multi Level Cell)
 (11, 10, 01 or 00)

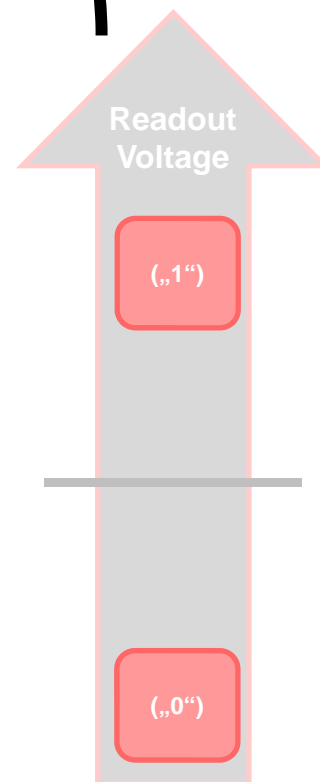


MLC



eMLC

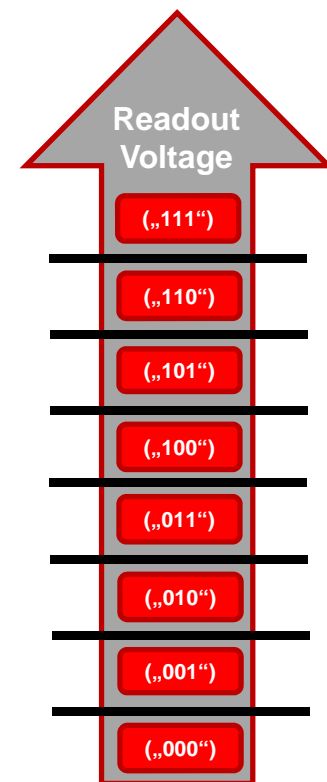
Enterprise MLC
 screening accurate devices



pSLC

Pseudo SLC
 Using MLC as SLC

TLC
(Triple Level Cell)
 (000,001,010,011,
 100,101,110,111)



TLC

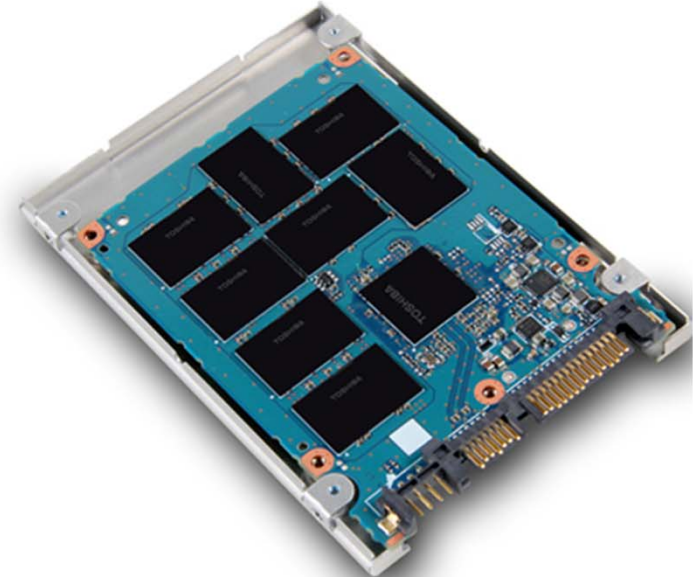
Write Endurance of NAND Flash

- **Write Endurance of raw flash components**

- SLC NAND Flash: ~100k erase cycles
- MLC NAND Flash: 5~10k erase cycles
- TLC NAND Flash: ~1k erase cycles

- Hard Disk Media: >10 Billion (*) cycles

(*) no limit on media, 10 Billion =
theoretical max of workload x years



Write Endurance Management in SSD

- **Static/Dynamic Wear Leveling**

- Dynamic: Write to empty/erased blocks (with lowest erase count). „Static“ blocks remain (ie USB-Stick)
- Static: Also move „static“ blocks with low erase count (SSD)

- **Capacity Over-Provisioning**

- SSD Capacity in GByte (10^9 Byte), internal flash in GiByte (2^{30} Byte)
→ 7.4 % higher internal capacity
- 240 GB SSD capacity using 256 GiB Flash (120 vs 128, 480 vs 512 etc.)
- 200 GB vs 256 GiB Flash (100 vs 128, 400 vs 512 etc.)

- **Bad Block Management**

- If write fails in one block, another block is assigned

- **Garbage Collection (internal) and TRIM (from operating system)**

Endurance: THE Criteria for SSD

- **TBW („Total Byte Written“)**
 - Total amount of data writable into SSD
 - Depending on capacity: Large capacity = higher TBW
 - Difficult to compare
- **DWPD („Disk Write per Day“)**
 - How often the entire capacity of the disk can be **written**
 - **per day**
 - over warranty **lifetime**
 - More complicated, but better to compare and classify

$$\text{TBW [TB]} = \text{DWPD} \times \text{Capacity [TB]} \times 365 \text{ Days} \times 3(5) \text{ Years}$$

$$\text{DWPD} = \frac{\text{TBW [TB]}}{\text{Capacity [TB]} \times 365 \text{ Days} \times 3(5) \text{ Years}}$$

SSD Device Mapping by Endurance Class

- **~0.1 DWPD (SATA) for 3 years** \$
 - Consumer (Laptop/Desktop), Dedicated Boot

- **1 DWPD (SATA or SAS) for 5 years** \$\$\$
 - „Read Intensive“, „warm data“, booting
 - Content Delivery, Streaming („write once a while, read many“)

- **10 DWPD (mainly SAS) for 5 years** \$\$\$\$\$\$
 - Server Mainstream, Database

- **30 DWPD (SAS) for 5 years** \$\$\$\$\$\$\$\$\$\$\$\$
 - Logging, Acceleration, Caching

Remark:

- Workload Assumption: 4kB random writes
- „Sequential Workload“ allows significantly higher TBW/DWPD.

SSD Performance

- **Random Data Rate (IOPS)**

- SSD: IOPS = f(memory interface & controller). **No seek time** like HDD !!!
- 4kB random read: > 100.000 IOPS
- 4kB random write: > 30.000 IOPS
- 4kB random r/w 70%/30% **> 50.000 IOPS.**
- 15krpm HDD was **~ 300 IOPS**

- **Sequential Data Rate Internal (MB/s)**

- 64kB block sequential read: ~900MB/s (eSSD)
- 64kB block sequential write: ~400MB/s (eSSD)
- 15krpm HDD was ~300MB/s

To Remember About SSD

- **SSD are really fast.**

- Fastest HDD 300 IOPS, SSD up to 100.000 IOPS



- **HDD and SSD are different ! No 1:1 Exchange**

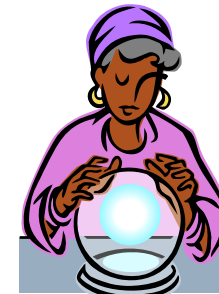
- **SSD Application is sensitive to „Workload“**

- **Client SSD** don't work in RAID/Cache Applications



- **DWPD is the key Criteria**

- DWPD depends on Flash Quality.
 - Selection/Screening for Enterprise Level MLC
 - → Buy SSD from Flash Manufacturer !



- **HDD fails by Spindle Motor Failure – unpredictable**

- **SSD fails by reaching max. Write Endurance – very predictable**

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