MIT’s Dudley Buck creates first semiconductor NVM from ferroelectric crystals.

Bell Labs’ Merz and Anderson create monolithic 256-bit FRAM ferroelectric NVM, the first monolithic memory chip.

C.T. “Tom” Sah of Fairchild envisions floating gate NVM using charge storage on the gate electrode of a MOS tetrode transistor.

Edgar A. Sack, Ting L. Chu and others of Westinghouse use a Metal-Nitride-Oxide-Silicon (MNOS) structure as a charge-trapping element.

Dawon Kahng and Simon Sze (2014 FMS Lifetime Achievement Awardee) invent the Non-Volatile Memory Floating Gate at Bell Labs; this is published as “A Floating Gate and Its Application to Memory Devices” (Bell System Technical Journal).

John R. Szedon (2020 FMS Lifetime Achievement Awardee) and Ting L. Chu of Westinghouse propose using a charge trap as a nonvolatile memory bit at the IEEE Solid State Device Research Conference.

Stanford R. Ovshinsky announces the Ovonic Memory Switch, the basis for 3D XPoint memory as announced by Intel and Micron in 2015, and as later productized by Intel as Optane.
Toshiba’s Iizuka, Masuoka and others introduce the first double-layered polysilicon memory cell with Floating Gate electrical erase as Stacked-Gate Avalanche-Injection Type MOS (SAMOS) Memory at International Conference on Solid State Devices and Materials. Fujio Masuoka goes on to receive the 2013 FMS Lifetime Achievement Award.

Dov Frohman-Bentchkowsky invents the Erasable Programmable Read-Only Memory (EPROM) at Intel; this is presented at the 1971 IEEE International Solid-State Circuits Conference (ISSCC), and is published as “Memory Behavior in a Floating-Gate Avalanche-Injection MOS (FAMOS) Structure” in April 1971 (Applied Physics Letters), which cited the 1967 Kahng/Sze Bell Labs Floating Gate publication.

After work with Stanford R. Ovshinsky, Intel’s Gordon Moore co-authors article for Electronics Magazine on the first demonstration of Phase Change Memory (PCM), the NVM technique used by 3D XPoint as announced by Intel and Micron in 2015, and as later productized by Intel as Optane.

General instrument ships EAROM, the first commercial EEPROM.

Hitachi files for patent on NAND-type MROM.

Portable digital camera invented at Eastman Kodak Company with digital image storage on a cassette tape.
Eli Harari (2012 and 2022 FMS Lifetime Achievement Awardee), then of Hughes Microelectronics, files for patent on first practical floating gate EEPROM using thin SiO₂ and Fowler-Nordheim tunneling for program and erase.


Patent granted to TI’s Gerald Rogers for mask ROM configured as a NAND array to reduce chip area and cost.

Hughes Microelectronics introduces first CMOS NOVRAM 256-bit chip (non-volatile SRAM) employing Fowler Nordheim floating gate EEPROM at IEEE ISSCC.

George Perlegos (2017 FMS Lifetime Achievement Awardee) designs the Intel 2816, which was introduced in 1980 and became the first commercially successful EEPROM.
Hughes Microelectronics introduces the 3108, first CMOS EEPROM 8Kb chip employing Fowler-Nordheim tunneling. Intel introduces the 2816, a 16Kb HMOS EEPROM with a FLOTOX (floating gate tunnel oxide) structure employing Fowler-Nordheim tunneling, at IEEE ISSCC. Fujitsu files for patent on improvements to Hitachi’s 1975 MROM.

British scientist and inventor Kane Kramer designs first digital audio player (IXI) based on magnetic bubble memory chips.

SEEQ Technology introduces the 5213, the first EEPROM with an on-chip charge pump for in-system write and erase, an invention used in all flash memory devices. Ramtron introduces first commercial FRAM NVM.

Intel introduces 2817A 16Kb EEPROM.

Intel begins flash process development.

George Perlegos (2017 FMS Lifetime Achievement Awardee) founds ATMEL (which stands for “Advanced Technology for Memory and Logic”).

Exel files for patent on first NOR Flash cell.

NEC’s Kitamura files for first MLC (Multi-Level Cell) EPROM patent (in Japan).

Flash card concept introduced with ECC and on-card controller by Intel.

Intel forms unit focusing on solid state drives.

R. Stewart et. al. of RCA publish first paper on a NAND-configured UV-EPROM at IEEE VLSI Symposium.

Toshiba’s Fujio Masuoka (2013 FMS Lifetime Achievement Awardee) presents IEEE IEDM paper on NAND flash memory; the 35th anniversary of his inventive paper was celebrated at the 2022 FMS.

Intel introduces NOR flash chips.
SunDisk founded by Eli Harari (2012 and 2022 FMS Lifetime Achievement Awardee) to develop new “System Flash” architecture combining embedded controller, firmware and flash to emulate disk storage, and files for first MLC (Multi-Level Cell) flash patent.

First flash memory sampled by Intel as 1Mb NOR chips. Intel’s Design Team of Richard Pashley, Stefan Lai, Bruce McCormick and Niles Kynett go on to receive 2012 FMS Lifetime Achievement Awards.

Intel and Psion design flash-based mobile PC.

First flash-based digital camera, Fuji DS-1P, demonstrated. 150mm wafers used.

SunDisk files for patent on “System Flash” which describes on-chip cell management.

M-Systems founded and introduces Flash Disk concept (precursor to flash SSDs). M-Systems co-founders Dov Moran and Aryeh Mergi went on to receive 2018 FMS Lifetime Achievement Awards.

Intel ships 512kb and 1Mb NOR flash.

Psion flash-based PC introduced.

Microsoft introduces Flash File System in joint effort with Intel.

DigiPro introduces 8MB NOR Flashdisk at Comdex.

Western Digital and SunDisk pioneer NOR-based SSD fully emulating ATA HDD.

Personal Computer Memory Card International Association (PCMCIA) founded.

Silicon Storage Technology (SST) founded to produce NOR SuperFlash, compatible with a CMOS logic process.

Sony introduces EReader using flash memory.

Kodak flash-based camera prototypes shown.

PCMCIA sets standard on ATA PC Card form factor and pinout, using SunDisk “System Flash” specification for full HDD compatibility.

Intel 1MB and 4MB linear flash PCMCIA cards introduced.

Intel introduces 2Mb NOR chip.

SunDisk introduces first NOR flash SSD: 20MB 2.5”, fully compatible with Conner peripherals 2.5” ATA HDD.

Toshiba verifies NAND flash chip operation, and begins 4Mb and 16Mb NAND flash chip development.

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Toshiba verifies NAND flash chip operation, and begins 4Mb and 16Mb NAND flash chip development.
Toshiba ships first mass-produced NAND flash chips (4Mb).
Information Storage Devices introduces flash-based voice recorder chip.
AMD introduces its first NOR product.
Fujitsu introduces its first NOR product.
M-Systems introduces TrueFSS, the first flash memory card FTL; this was later adopted by the PCMCIA as its FTL.
Intel launches second-generation FFS2.
Intel introduces 8Mb NOR flash chips and 4Mb-20Mb linear flash memory cards.
Intel introduces 1Mb ‘boot block’ NOR flash with sectors for BIOS applications—first use of internal write state machine to manage flash write algorithm.
SunDisk introduces CompactFlash card.
Norris Communications introduces Flashback, the first portable digital voice recorder with flash memory.
0.5 micron process announced.
SunDisk introduces 18Mb Serial NOR flash chip for SSD applications.
M-Systems introduces NOR-based DiskOnChip.

Flash (NOR and NAND) revenues exceed $1B.
Casio introduces the QV-11 digital camera with flash rather than film or floppy.
Mitsubishi introduces DiNOR.
SunDisk changes name to SanDisk.
CompactFlash Association (CFA) founded.
<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
</tr>
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<tbody>
<tr>
<td>1996</td>
<td>Toshiba introduces SmartMedia Memory Card (also called Solid State Floppy Disk Card).</td>
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<tr>
<td></td>
<td>Samsung starts shipping NAND flash.</td>
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<tr>
<td></td>
<td>$2.6B in flash memory revenues, 163.063% growth in 10 years.</td>
</tr>
<tr>
<td>1997</td>
<td>Datalight introduces &quot;FlashFX&quot; flash management software supporting NOR and NAND in a single driver.</td>
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<td></td>
<td>SanDisk introduces world's first MLC (2 bits/cell) flash chip (80 Mb) in a CompactFlash (CF) card.</td>
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<td></td>
<td>Palm introduces flash memory-based PDA.</td>
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<td></td>
<td>Lexar Media spins off from Citrus Logic.</td>
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<td></td>
<td>USB Association (USBA) founded.</td>
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<tr>
<td>1998</td>
<td>NOR revenues exceed $2B.</td>
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<tr>
<td></td>
<td>250nm process announced.</td>
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<td></td>
<td>SanDisk and Siemens introduce MultiMedia Card (MMC and MMCplus).</td>
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<tr>
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<td>Diamond Rio introduces PMP300 MP3 player.</td>
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<td>MultiMediaCard Association (MMCA) founded by 14 companies.</td>
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<td>Apple iMac introduced without floppy but with USB, encouraging USB-based external storage.</td>
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<td>USB Implementers Forum first publishes USB Mass Storage Class spec (finalized in 1999) to standardize USB-based storage.</td>
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<td></td>
<td>Micron announces NOR products.</td>
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<td></td>
<td>Hagiwara Sys-Com begins shipping FlashGate, a USB SmartMedia flash memory card drive.</td>
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<td></td>
<td>Dov Moran (2018 FMS Lifetime Achievement Co-Awardee) is co-inventor on M-Systems patent filing for USB flash drive.</td>
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<tr>
<td></td>
<td>Panasonic (Matsushita), SanDisk and Toshiba introduce SD memory card.</td>
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<tr>
<td>1999</td>
<td>NOR revenues exceed $4B.</td>
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<td></td>
<td>Over one billion flash chips ship.</td>
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<td></td>
<td>Toshiba and SanDisk create flash memory manufacturing joint venture.</td>
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<td>SanDisk and Siemens introduce MultiMedia Card (MMC and MMCplus).</td>
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Flash (NOR and NAND) revenues exceed $10B.
M-Systems (working with IBM) and Trek Technology introduce USB flash drives.
Intel ships its one-billionth flash unit.
160nm process announced.
Panasonic (Matsushita), SanDisk and Toshiba establish SD Association to standardize and promote the Secure Digital memory card.
SLC NAND-based SD cards introduced in 8MB to 64MB capacities.

$10,637,231,000

Olympus and FujiFilm introduce xD-Picture Card.
MMCmobile card introduced by MMCA (MultiMediaCard Association).
Sony and SanDisk jointly introduce the Memory Stick PRO and half-size Memory Stick PRO Duo cards.
M-Systems introduces Mobile DiskOnChip, the first SSD in a chip; this was used in handsets by Nokia, Motorola and Ericsson.

NAND revenues exceed $1B.
Toshiba and SanDisk announce 3Gb MLC NAND.
SanDisk introduces first NAND "System Flash" product.
Hitachi introduces AG-AND.
Samsung begins mass production of 512Mb flash memory device.
Saifun develops NROM with charge trap flash structure, the basis for Spansion’s MirrorBit.

$7,766,797,000

AMD introduces MirrorBit using hot electron injection-based charge trap flash.
Cypress introduces Programmable System on Chip (PSoC) with first embedded SONOS using quantum mechanical tunneling-based charge trap flash.
130nm process announced.

$7,594,502,000

SanDisk introduces miniSD card.
Sony and SanDisk jointly introduce Memory Stick PRO Micro.
Spansion spins out of AMD and Fujitsu.
Samsung introduces TaNOS structure at IEEE IEDM, a technology later used in 3D NAND.

$11,739,282,000

Flash Memory Summit is not responsible for any inaccuracies in this Timeline.

Email suggested additions and changes to timeline@FlashMemorySummit.com
NAND prices drop below DRAM prices. U3 software system for USB flash drives introduced by SanDisk and M-Systems. SanDisk and Motorola introduce TransFlash card, now the microSD card. Data allotted introduces multi-threaded FlashFX Pro management software to support multimedia NAND devices. Spansion announces MirrorBit Quad 4-bit NOR. 90nm process announced. Hynix and ST Micro form flash joint venture. Hynix NAND product introduced. Infineon NAND product introduced based on Saifun Charge Trap Flash. Panasonic and Sanyo introduce first flash-based camcorders. SanDisk introduces Flash Sansa MP3 players. Freescale (later Evergreen) ships first commercial MRAM NVM. Pankaj Mehra and Sam Fineberg of Hewlett-Packard present Persistent Memory paper at ACM/IEEE Computer Society’s 18th IPDPS.

NAND revenues exceed $10B. Over three billion flash chips ship. NAND GB shipments overtake those of DRAM. Apple introduces first two flash-based iPods: iPod shuffle and iPod nano. Microsoft introduces Hybrid Hard Disk Drive concept. MMCmicro card introduced by MMCA. 70nm process announced. Micron introduces NAND product.


Flash revenues exceed $22B, almost 9 times 1997 revenues. NAND revenues exceed $14.5B. Non-Volatile Memory Host Controller Interface (NVMHCI) Working Group formed, with Intel’s Amber Huffman as Chair. Toshiba introduces eMMC NAND. IMFT begins shipping 50nm NAND flash. Toshiba introduces first SATA-based MLC SSD. Apple introduces the iPhone. Fusion-io announces 640GB ioDrive MLC NAND-based PCIe x4 board. BitMICRO launches 3.5" SSD with capacity of 1.6TB (for military applications). Spansion acquires Saifun. Several laptop MLC SSDs introduced with up to 128GB storage. Dell introduces SSD option for laptop models. Sub-$200 netbook computers introduced with flash memory storage. Microsoft introduces flash-based Zune Player. Seagate announces Hybrid Storage Alliance. Seagate introduces first Hybrid HDD, the Momentus Hybrid. MMCA/JEDEC eMMC spec published. Toshiba presents 3D flash BiCS memory at ACM/IEEE VLSI Symposium.
NVMHCI 1.0 Spec released by Intel. SanDisk introduces ABL to enable high speed MLC, TLC and X4 NAND. 34nm process announced by Intel and Micron. Toshiba introduces first 512GB MLC SATA-based SSD. Intel and STMicro spin off Numonyx. IBM demos first “Million IOPS” array. EMC announces use of flash-based SSDs for enterprise SAN applications. Apple introduces SSD-based MacBook Air without an HDD option. Micron, Samsung and Sun Microsystems announce high-endurance flash memory. Violin Memory introduces first fully flash-based storage appliance. Samsung announces 150GB 2.5” MLC SSD with SATA II interface. Several companies announce MLC flash SSDs with up to 256GB for notebook apps. Micron introduces first serial NAND flash. Apple sells one million flash-based iPhones in 3 days. MMCA merges into JEDEC. SNIA Solid State Storage Initiative (SSSI) formed. HGST releases first SSD with a SAS interface.

2008

$18,435,970,000

Intel and Micron introduce 34nm TLC NAND. Samsung introduces first full HD camcorder with 64GB SSD. Seagate enters SSD market. SandForce introduces first compression-based SSD controller. Virident and Schooner introduce first flash-based application appliances for the data center. Pillar Data converts Axiom SANs to SSD. SanDisk and Toshiba present 4-bit/cell flash at IEEE ISSCC. WD acquires SiliconSystems and gets into SSD business. NVELO introduces first PC flash caching software “Dataplex.” SanDisk introduces 100-year flash storage vault. AgigA ships NAND-backed DIMM.

2009

$19,302,693,000


2010

$26,734,247,000


2011

$28,123,615,000

SanDisk and Toshiba announce 19nm process in 128Gb chips at IEEE ISSCC.

UltraBook ship with Smart Response Technology (SRT) SSD cache.

Maxim and Winbond enter NAND business.

Seagate introduces SSHD, a Hybrid Hard Drive (HHD) pairing flash with an HDD.

Eplida introduces ReRAM.

Micron and Intel introduce 20nm 128Gb NAND chip using hi-planar cell.

SK hynix formed upon using hi-k planar cell.

2012

$ 28,213,759,000

Achievement Award.

receives FMS Lifetime

SanDisk founder Eli Harari

SNIA forms NVM

JEDEC and ONFi

HGST.

Western Digital acquires

acquires Ramtron.

Cypress Semiconductor

Memory Systems.

IBM acquires Texas

PCIe enterprise SSD.

Micron introduces 2.5"

Cade caching software.

LSI introduces Nytro flash

with MegaRAID Cache-Code caching software.

Micron introduces 2.5"
Pcie enterprise SSD.

IBM acquires Texas Memory Systems.

Cypress Semiconductor acquires Ramtron.

Western Digital acquires

HGST.

JEDEC and ONFI
introduce toggle mode.

SNIA forms NVM
Programming Model V1.0.

SanDisk founder Eli Harari
receives FMS Lifetime Achievement Award.

Samsung announces 24-layer 3D V-NAND at FMS and demos it in a 1TB SSD.

11 companies participate in first NVMe Plugfest.

Diablo Technologies announces Memory Channel Storage tech.

SMART Storage Systems incorporates Diablo Tech designs into ULLtraDIMM.

SNIA NVDIMM SIG formed; many NVDIMM products introduced.

Western Digital and SanDisk introduce SSHD using SSD combined with a Hard Disk Drive.

Toshiba introduces line of SSDs.

Everspin Technologies announces shipments of STT MRAM.

Micron and others sample 16nm flash memory.

M.2 PCIe interface formalized.

Western Digital acquires 3tec, Vinylent, Velobit.

SanDisk acquires SMART Storage Systems.

NV/IMurance introduces software to extend flash endurance.

Micron acquires Elpida.

Intel introduces Intel Cache Acceleration Software.

First UFS devices sampled by Toshiba at 8GB.

Panasonic ships first commercial embedded ReRAM in an MCU.

Adesto ships Mavia CBRAM; first commercial stand-alone ReRAM.

SNIA publishes NVM Programming Model V1.0.

Fujo Masuoka, formerly of Toshiba, receives FMS Lifetime Achievement Award.

SanDisk and Toshiba announce 3D NAND production facilities.

SanDisk introduces 4TB Enterprise SSD.

Intel ships first NVMe SSD.

SanDisk announces 128GB microSD card, a 100X increase in capacity on device's 10th anniversary.

IBM announces eXFlash DIMMs using SanDisk ULLtraDIMM's implementation of Diablo Memory-Channel Storage technology.

Samsung rolls out second generation 3D V-NAND with 32 layers.

Spanior introduces HyperFlash NOR with 333 MB/s HyperBus.

Toshiba acquires OCZ.

Everspin introduces and ramps production of ST-MRAM.

Samsung announces 3-bit/cell 3D NAND SSDs.

Adesto ships one-millionth CBRAM.

SK hynix acquires Violin Memory's PCIe SSD business.

Seagate acquires LSI/Avago storage business.

SanDisk acquires Fusion-io.

HGST acquires mijra.

Samsung announces

Flash Memory Summit's 10th conference.

SanDisk introduces InfiniFlash storage system.

Cypress Semiconductor acquires Spanscion.

Toshiba, Samsung, and SanDisk announce 48-layer 3D NAND.

Intel and Micron announce 256Gb 3D NAND.

Samsung introduces first NVMe m.2 SSDs.

SanDisk introduces 200Gb microSDXC UHS-1 card.

Cypress introduces 48mb serial FRAM.

Intel and Micron announce 3D XPoint Memory.

Intel announces 3D XPoint-based "Optane" DIMMs and SSDs.

Micron introduces device with CMOS Under 3D NAND Array (CUA).

SanDisk introduces 200GB microSD card.

Mellanox and partners demonstrate pre-standard NVMe over Fabric (NVMe-oF).

Pure Storage has IPO.

JEDEC publishes first DDR4

NVDIMM-N Persistent Memory Module spec.

LightNVM and Open-Channel SSD support added to Linux kernel.

Bob Norman, formerly of SanDisk and Micron, receives FMS Lifetime Achievement Award.

2013

$ 29,797,262,000

Achievement Award.

Lifetime Achievement

Bell Labs, receives FMS

Simon Sze, formerly of

Proximal Data.

Samsung acquires

HGST acquires Skyera.

Fusion-io.

SanDisk acquires

SMART Storage Systems.

Micron acquires Elpida.

Endurance.

NVMdurance introduces

Storage Systems.

SanDisk acquires SMART Storage Systems.

Toshiba introduces line of Hard Disk Drive.

SanDisk introduce SSHD

Western Digital and

introduced.

many NVDIMM products

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Many companies introduce 3D NAND SSDs.

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2014

$ 30,236,484,000

Achievement Award.

receives FMS Lifetime

SanDisk and Micron,

Bob Norman, formerly

of SanDisk and Micron,

addes to Linux kernel.

Bob Norman, formerly of SanDisk and Micron, receives FMS Lifetime Achievement Award.

2015

$ 31,053,183,000

Achievement Award.

receives FMS Lifetime

SanDisk and Toshiba, formerly

FMS Lifetime Achievement Award.

2017

Flash Memory Summit’s 15th conference (held as a virtual online-only event).

WDC ships 112-layer BICS 3D NAND as 512 Gbit TLC part.

KIOXIA ships first Automotive UFS at 512GB density.

Lightbits Labs ships first clustered, redundant, scale-out NVMe/TCP software solution.

Infineon acquires Cypress Semiconductor.

KIOXIA acquires LiteOn.

NVMe ZNS Command Set Spec V1.0 published.

NVMe Computational Storage Task Group formed.

Open Compute Project (OCP) publishes NVMe Cloud SSD Spec V1.0.

PCI-SIG releases PCIe 6.0 spec.

Universal Chiplet Interconnect Express (UCIe) 1.0 Spec released to standardize die-to-die interconnects.

JEDEC publishes JEDEC publishes HBM3 update to High Bandwidth Memory (HBM) DRAM standard.

Micron ships first 176-layer QLC 3D NAND and announces 232-Layer TLC 3D NAND.

Lightbits Labs ships first clustered NVMe/TCP software-defined public cloud storage solution.

Yan Li of Western Digital receives FMS SuperWomen in Flash Award.

Yoshishige Kitamura (formerly of NEC), SanDisk founder Eli Harari (2012 FMS Lifetime Achievement Awardee), and Greg Atwood (formerly of Intel, Numonyx, and Micron) receive FMS Lifetime Achievement Awards.

39th anniversary of NAND Flash: proposed by Toshiba’s Fujio Masuoka (2013 FMS Lifetime Achievement Awardee) in an IEEE IEDM paper; industry-wide celebration at Flash Memory Summit.

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