

Flash Memory Timeline

Dawon Kahng and Simon M. Sze 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); Simon M. Sze went on to receive the 2014 FMS Lifetime Achievement Award

Dov Frohman-Bentchkowsky invents the Erasable Programmable Read-Only Memory (EPROM) at Intel; this 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

Hughes Microelectronics files Eli Harari patent for first practical floating gate EEPROM using thin SiO₂ and Fowler Nordheim tunneling for program and erase; Eli Harari went on to receive the 2012 FMS Lifetime Achievement Award

1967

1970

1976

1977

Eli Harari of Hughes Microelectronics publishes "Conduction and Trapping of Electrons in Highly Stressed Thin Films of Thermal SiO₂" (Applied Physics Letters)

1978

Eli Harari of Hughes Microelectronics publishes "Dielectric Breakdown in Electrically Stressed Thin Films of Thermal SiO₂" (Journal of Applied Physics)

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

1979

IEEE Solid State Circuits publishes paper titled "An Electrically Alterable Non-Volatile Memory Cell Using Floating Gate Structure" by Guterman, Rinawi, Chieu, Holvorson, and McElroy of Texas Instruments

1980

Hughes Microelectronics introduces the 3108, first CMOS EEPROM 8Kb chip employing Fowler Nordheim tunneling

Intel introduces the 2816, 16Kb HMOS EEPROM employing Fowler Nordheim tunneling



Flash Memory Summit

1981

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

1982

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

1983

Intel introduces 2817A 16Kb EEPROM

1984

First paper describing flash EEPROM presented by Fujio Masuoka of Toshiba at IEEE International Electron Devices Meeting (IEDM) in San Francisco; Fujio Masuoka went on to receive the 2013 FMS Lifetime Achievement Award

Intel begins flash process development

ATMEL (Advanced Technology for Memory and Logic) is founded by George Perlegos, who went on to receive the 2017 Lifetime Achievement Award

1985

Exel files patent for first NOR Flash cell

1986

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

Intel forms unit focusing on solid state drives

1987

First NAND-type flash memory technology presented by Fujio Masuoka of Toshiba at IEEE International Electron Devices Meeting (IEDM)

Intel invents first Flash File System concept

Intel introduces NOR flash chips

1988

SunDisk founded to develop new "System Flash" architecture combining embedded controller, firmware and flash memory to emulate disk storage

SunDisk files first two MLC (Multi-Level Cell) flash patents

JPEG and MPEG standards released allowing economical production of digital cameras

Intel samples 1Mb NOR flash

Intel and Psion design flash-based mobile PC

First flash-based digital camera, Fuji DS-1P, demonstrated

150mm wafers used

Annual Revenue >

\$ 1,600,000

\$ 6,400,000

1989

\$ 25,600,000

SunDisk files System Flash patent

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

1990

\$ 100,000,000

Sony introduces EReader using flash memory

Kodak flash-based camera prototypes shown

NOR flash pricing in parity with DRAM pricing

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 world's first NOR flash SSD: 20MB 2.5", fully compatible with Conner peripherals 2.5" ATA HDD

1991

\$ 170,000,000

Toshiba develops world's first 4Mb NAND flash

Kodak ships DCS-100, its first DCS at \$13,000

Zenith, Poqet and HP palm-sized notebook computers using flash memory cards shown at Spring Comdex

1992

\$ 295,000,000

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 flash chip and 4MB-20MB linear flash memory cards

Intel introduces 1Mb "boot lock" NOR flash with sectors for BIOS applications—first use of internal write state machine to manage flash write algorithm

SunDisk introduces first serial 9Mb NOR Flash chip for SSD applications

PCs begin using flash for BIOS storage

Toshiba ships first mass-produced NAND (4Mb)

1993

\$ 505,000,000

Datalight introduces "Card Trick" flash management software

Apple introduces NOR flash-based Newton PDA

Intel introduces 16Mb and 32Mb NOR flash

Intel and Conner Peripherals introduce jointly-developed 5MB/10MB ATA flash disk drive

AMD introduces 5-volt-only NOR using negative gate erase

1994

\$ 864,805,000

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

1995

\$ 1,860,089,000

Casio introduces the QV-11 digital camera with flash rather than film or floppy

Mitsubishi introduces DiNOR

SunDisk introduces 34Mb Serial NOR Flash—first MLC flash chip for SSD applications

SunDisk changes name to SanDisk

Flash (NOR and NAND) revenues exceed \$1B

CompactFlash Association (CFA) founded

1996

\$ 2,610,603,000

Toshiba introduces SmartMedia Memory Card (also called Solid State Floppy Disk Card)

Samsung starts shipping NAND flash

Kodak DC-25 is first DSC with CompactFlash card

Datalight introduces "FlashFX" flash management software supporting NOR and NAND in a single driver

SanDisk introduces first flash cards with MLC serial NOR

Palm introduces flash memory-based PDA

0.35 micron process announced

\$2.6B in flash memory revenues, 163,063% growth in 10 years

Lexar Media spins off from Cirrus Logic

USB Association (USBA) founded

1997

\$ 2,701,678,000

SaeHan Information Systems introduces flash-based MPMan MP3 player

Sandisk and Siemens introduce MultiMedia Card (MMC and MMCplus)

Sony introduces the Memory Stick

First cell phones ship with flash memory

M-Systems introduces NAND-based DiskOnChip

200mm wafers begin production

500 million flash chips ship

Intel introduces 2-bit/cell 64Mb MLC StrataFlash

MultiMediaCard (MMC) unveiled by SanDisk and Siemens

1998

\$ 2,492,552,000

250nm process announced

NOR revenues exceed \$2B

SaeHan Information Systems and licensee Eiger ship world's first mass-produced MP3 player (MPMan) with 32MB

Diamond Rio introduces PMP300 MP3 player

Panasonic, SanDisk and Toshiba launch SD card

MultiMediaCard Association (MMCA) founded by 14 companies

1999

\$ 4,560,493,000

Toshiba and SanDisk create flash memory manufacturing joint venture

Micron announces NOR products

Over one billion flash chips ship

Dov Moran of M-Systems applies for patent on USB-based flash drive

NOR revenues exceed \$4B

Lexar Media introduces CompactFlash-to-USB JumpSHOT

2000

\$ 10,637,231,000

M-Systems (working with IBM) and Trek Technology introduce USB flash drives

Intel ships its one-billionth flash unit

160nm process announced

Flash (NOR and NAND) revenues exceed \$10B

SD Card Association founded

2001

\$ 7,594,502,000

Toshiba and SanDisk announce 1Gb MLC NAND

SanDisk introduces first NAND System Flash product

Hitachi introduces AG-AND

Samsung begins mass production of 512Mb flash memory device

NAND revenues exceed \$1B

2002

\$ 7,766,797,000

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

AMD introduces MirrorBit charge trap flash

130nm process announced

2003

\$ 11,739,282,000

SanDisk introduces miniSD card

Sony and SanDisk jointly introduce Memory Stick PRO Micro

Spansion spins out of AMD and Fujitsu

NAND revenues exceed \$5B

2004

\$ 2,492,552,000

U3 software system for USB flash drives introduced by SanDisk and M-Systems

NAND prices drop below DRAM prices

SanDisk and Motorola introduce TransFlash card, now the microSD card

Datalight 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

2005

2006

2007

2008

\$ 4,560,493,000

\$ 10,637,231,000

\$ 22,182,405,000

\$ 18,435,970,000

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

Over three billion flash chips ship

NAND GB shipments overtake those of DRAM

NAND revenues exceed \$10B

Intel introduces Robson Cache Memory (now called Turbo Memory)

Microsoft introduces ReadyBoost

SanDisk announces 3-bit MLC NAND technology

M-Systems announces 4-bit MLC technology

SanDisk announces microSDHC card

SanDisk acquires Matrix Semiconductor

SanDisk acquires M-Systems

Samsung and Seagate demonstrate first Hybrid Hard Disk Drives

IMFT formed by Intel and Micron to manufacture NAND flash

STEC acquires Gnutech

Spansion introduces ORNAND flash

56nm process announced

300mm wafers begin production

Micron acquires Lexar Media

Flash revenues exceed \$20B

First Flash Memory Summit held in San Jose

Toshiba introduces eMMC NAND

IMFT begins shipping 50nm NAND flash

Toshiba introduces first MLC SATA-based 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

NAND revenues exceed \$14.5B

Flash revenues exceed \$22B, almost 9 times 1997 revenues

Seagate announces Hybrid Storage Alliance

Seagate introduces first hybrid HDD, the Momentus PSD

MMCA/JEDEC jointly release e.MMC spec

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 MacBook Air

Micron, Samsung and Sun Microsystems announce high-endurance flash memory

Violin 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

Toshiba develops 3D NAND structure, BiCS

Apple sells one million flash-based iPhones in 3 days

MMCA merges into JEDEC

SNIA Solid State Storage Initiative (SSSI) formed

2009

\$ 19,302,693,000

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

Pliant introduces first SAS SSD

SanDisk and Toshiba present 4-bit/cell flash at 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

2010

\$ 26,734,247,000

Toshiba introduces 128GB SD card based on 16-chip stack

Intel, Micron introduce 25nm TLC and MLC NAND

Numonyx acquired by Micron

Microchip acquires SST

Samsung Electronics begins producing 64Gb 3-bit NAND

Samsung Electronics introduces high-speed 512GB SSD utilizing toggle-mode DDR NAND memory

Seagate announces first self-managed hybrid HDD, Momentus XT, with 4GB NAND flash and 500GB HDD storage

Universal Flash Storage Association (UFSA) founded

Email your suggested additions and changes to timeline@FlashMemorySummit.com

2011

\$ 28,123,615,000

LSI acquires SandForce

SanDisk acquires Pliant

IMFT introduces 20nm NAND flash

Intel announces Smart Response SSD caching for PCs

Seagate announces second generation Momentus XT hybrid HDD with 8GB NAND flash and 750GB HDD storage

Apple acquires Anobit

Fusion-io acquires IO Turbine

NVM Express organization established and NVMe Rev. 1.0 published

Richard Pashley, Stefan Lai, Bruce McCormick and Niles Kynett formerly of Intel receive FMS Lifetime Achievement Awards

2012

\$ 28,260,433,000

SanDisk and Toshiba announce 19nm flash memory enabling 128Gb chips

Ultrabooks begin to ship with Smart Response SSD cache

Macronix and Winbond enter NAND flash business

Seagate Technology introduces SSHD combining flash memory with an HDD

Elpida introduces ReRAM

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

SK hynix formed upon SK Telecom's acquisition of controlling interest in Hynix Semiconductor

MOSAID samples 333GB/s HL-NAND

Adesto acquires ATMEl's Serial NOR business

Spansion introduces 8Gb NOR chip

DensBits Technologies introduces Memory Modem

Proximal Data introduces AutoCache

SanDisk acquires FlashSoft

EMC acquires XtremIO

OCZ acquires Sanrad

Samsung acquires NVELO

Intel acquires Nevex and introduces CacheWorks

LSI introduces Nytro flash with MegaRAID CacheCade caching software

Micron introduces 2.5" PCIe enterprise SSD

IBM acquires Texas Memory Systems

SanDisk founder Eli Harari receives FMS Lifetime Achievement Award

2013

\$ 30,265,273,000

Samsung announces availability of 24-layer 3D V-NAND and demonstrates 1TB SSD at FMS

Diablo Technologies announces Memory Channel Storage technology

SMART Storage Systems incorporates Diablo Technologies designs into ULLtraDIMM

SNIA NVDIMM SIG formed; many flash-based NVDIMM products introduced

Western Digital and SanDisk introduce SSHD using iSSD combined with an SDD

Toshiba introduces line of SSHDs

Everspin Technologies announces shipments of STT MRAM

Micron and other companies sample 16nm flash memory

SanDisk releases CFast 2.0 memory card, fastest memory card for professional video

M.2 PCIe interface formalized

Western Digital acquires sTec, Virident and Velobit

SanDisk acquires SMART Storage Systems

NVMdurance introduces software to extend flash endurance

Micron acquires Elpida

Intel introduces Intel Cache Acceleration Software

First NVMe devices from Samsung and SanDisk

Fujio Masuoka, formerly of Toshiba, receives FMS Lifetime Achievement Award

2014

\$ 30,711,394,000

Samsung, SanDisk and Toshiba announce 3D NAND production facilities

SanDisk introduces 4TB Enterprise SSD

SanDisk announces 128GB microSD card, a 1000x 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

Spansion introduces HyperFlash NOR with 333 MB/s HyperBus

Toshiba acquires OCZ

Everspin introduces and ramps production of ST-MRAM

Samsung introduces 3-bit/cell 3D NAND SSDs

Adesto ships one-millionth CBRAM

SK hynix acquires Violin's PCIe SSD business

Seagate acquires LSI/Avago storage business

SanDisk acquires Fusion-io

HGST acquires Skyera

Samsung acquires Proximal Data

Simon Sze, formerly of Bell Labs, receives FMS Lifetime Achievement Award

2015

\$ 31,053,183,000

SanDisk introduces InfiniFlash storage system

Cypress Semiconductor acquires Spansion

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 4MB 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 Fabrics (NVMe-oF)

Pure Storage has IPO

JEDEC publishes first NVDIMM-N standard for Persistent Memory Modules

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

Flash Memory Summit 10th Anniversary

2016

\$ 33,423,128,000

Micron, Intel, Toshiba, SanDisk and SK hynix ship 3D NAND

XMC breaks ground on first China-owned NAND flash lab

Micron introduces 768Gb 3D NAND

Western Digital acquires SanDisk

Everspin announces 256Mb MRAM chips

IBM adapts TLC to PCM

Samsung ships 48-layer 3D NAND

NVMe-oF (NVM Express over Fabrics) Rev. 1.0 published

NVMe-oF products demonstrated by at least 12 vendors

Toshiba introduces Through-Silicon Via (TSV) NAND

Spin Transfer Technologies delivers fully functional ST-MRAM samples

Micron launches Xccela Consortium

Toshiba ships industry's first NVMe BGA "SSD on a chip"

Western Digital demonstrates prototype of the world's first 1TB SDXC card

Kinam Kim, President of System LSI / Semiconductor Business at Samsung, receives FMS Lifetime Achievement Award

2017

2018

2019

2020

\$ 49,727,000,000

\$ 56,227,000,000

Microchip ships its 75-billionth SST SuperFlash-based device

SK hynix announces 72-layer 3D NAND

Toshiba migrates all new SSDs to 64-layer BiCS FLASH TLC

Intel ships Optane (3D XPoint) SSD

Violin Memory goes private

HPE acquires Nimble Storage and Simplivity

Micron ships first string-stacked 3D NAND

Samsung and Toshiba/WD announce 96-layer 3D NAND

NGD Systems ships NVMe 24TB Computational Storage device

Everspin samples 1Gb STT MRAM chip

Global Foundries introduces embedded eMRAM

Flash Memory market exceeds size of entire 1990 semiconductor market

WD develops TLC on 64-layer 3D NAND

JEDEC and SNIA win FMS Award for NVDIMM-N Standard

ScaleFlux is first to deploy production-qualified Computational Storage

2012 Lifetime Achievement Awardee Eli Harari inducted into National Inventors Hall of Fame

George Perlegos, formerly of Intel, SEEQ and ATMEL, receives FMS Lifetime Achievement Award

Cypress introduces 16Mb FRAMs

Toshiba completes \$18B memory business sale

Samsung launches high-speed Z-SSD

Micron ships Enterprise SSD using QLC and 1Tb 3D NAND die

Hyperstone introduces flash controllers with AI and Machine Learning

Intel samples Optane DC Persistent Memory

China's "Big Fund" Phase 2 targets over \$30B for semiconductor investments

NVMe/TCP Transport Binding spec ratified by NVMe WG

SNIA forms Computational Storage Technical Work Group (TWG)

Gyr Falcon Technology ships AI accelerator incorporating first use of TSMC's eMRAM

Dov Moran and Aryeh Mergi, M-Systems co-founders, receive FMS Lifetime Achievement Awards

NGD Systems ships industry's first scalable ASIC-based Computational Storage NVMe SSD

Samsung announces commercial production of eMRAM on 28nm FD-SOI process

Lightbits Labs ships industry's first commercial NVMe/TCP software-defined disaggregated storage solutions

YMTC samples 32-layer "Xtacking" NAND

Intel ships Optane (3D XPoint) memory on DIMMs

Micron ships industry's first QLC enterprise SSDs

Intel ships SSDs with both Optane (3D XPoint) and QLC NAND

All major vendors ship or sample 96-Layer NAND

All leading foundries produce embedded MRAM

Trade tensions brew between US and China

Open-Channel SSDs evolved to standardization as NVMe Zoned Namespaces (ZNS)

Sanjay Mehrotra of Micron, and formerly of Intel, SEEQ, IDT, ATMEL, SanDisk and WD, receives FMS Lifetime Achievement Award

FMS 2020 August 4-6, Santa Clara Convention Center

