<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>1952</td>
<td>MIT's Dudley Buck creates first semiconductor NVM from ferroelectric crystals</td>
</tr>
<tr>
<td>1955</td>
<td>Bell Labs' Merz and Anderson create monolithic 256-bit FRAM ferroelectric NVM, the first monolithic memory chip</td>
</tr>
<tr>
<td>1961</td>
<td>C.T. “Tom” Sah of Fairchild envisions floating gate NVM using charge storage on the gate electrode of a MOS tetrode transistor</td>
</tr>
<tr>
<td>1965</td>
<td>Dov Frohman writes Berkeley PhD thesis “Charge Transport and Trapping in MNOS Structures and its Memory Applications” and builds a 9-bit prototype</td>
</tr>
<tr>
<td>1966</td>
<td>Edgar A. Sack, Ting L. Chu and others of Westinghouse use a Metal-Nitride-Oxide-Silicon (MNOS) structure as a charge-trapping element</td>
</tr>
<tr>
<td>1967</td>
<td>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</td>
</tr>
<tr>
<td>1968</td>
<td>John R. Szedon and Ting L. Chu of Westinghouse propose using a charge trap as a nonvolatile memory bit at the IEEE Solid State Device Research Conference</td>
</tr>
<tr>
<td>1970</td>
<td>Stanford R. Ovshinsky announces the Ovonic Memory Switch, the basis for 3D XPoint memory as later productized by Intel as Optane</td>
</tr>
<tr>
<td>1971</td>
<td>Dov Frohman-Bentchkowsky invents the Erasable Programmable Read-Only Memory (EPROM) at Intel; this is presented at the 1971 IEEE 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</td>
</tr>
<tr>
<td>1968</td>
<td>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</td>
</tr>
</tbody>
</table>
Toshiba’s Iizuka, Masuoka and others introduce first double-layered polysilicon memory cell (SAMOS) with Floating Gate electrical erase at International Conference on Solid State Devices and Materials

1972

1974

1975

1976

1977

1978

1979

1980

General Instrument ships EAROM, the first commercial EEPROM

Hitachi files patent for NAND-type MROM

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

P.C.Y. Chen of Fairchild introduces SONOS charge trap NVM cell in IEEE Transactions on Electron Devices

Hughes Microelectronics introduces first CMOS NOVRAM 256-bit chip employing Fowler Nordheim tunneling

P.C.Y. Chen of Fairchild introduces SONOS charge trap NVM cell in IEEE Transactions on Electron Devices

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


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

Fujitsu files patent with improvements to Hitachi’s 1975 MROM

Hughes introduces 8K-bit EEPROM
British scientist and inventor Kane Kramer designs first digital audio player (IXI) based on magnetic bubble memory chips.

SEIQ 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.

Ramtron introduces first commercial FRAM NVM.

Intel introduces 2817A 16kbit EEPROM.

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.

Exel files patent for first NOR Flash cell.

Intel introduces 1Mb NOR flash chips.

Toshiba’s Fujio Masuoka presents IEEE IEDM paper on NAND flash memory.

Intel forms unit focusing on solid state drives.

RCA’s VLSI Tech Symposium paper on first NAND-type EEPROM.

Intel samples 1Mb NOR flash.

Intel and Psion design flash-based mobile PC.

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 allowing economical production of digital cameras are published.

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

150mm wafers used.
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 introduces 1MB and 4MB linear flash PCMCIA cards introduced
SunDisk introduces first serial 9Mb NOR Flash chip for SSD applications
Toshiba develops world’s first 4Mb NAND flash
Kodak ships DCS-300, its first DCS at $13,000
Zenith, Poqet and HP palm-sized notebook computers using flash memory cards shown at Spring Comdex
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 8Mb NOR Flash chip for SSD applications
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
SanDisk introduces CompactFlash card
Norris Communications introduces Flashback, the first portable digital voice recorder with flash memory
0.5 micron process announced
SanDisk introduces 18Mb Serial NOR flash chip for SSD applications
M-Systems introduces NOR-based DiskOnChip
Casio introduces the QV-11 digital camera with flash rather than film or floppy
Mitsubishi introduces DNOR
SunDisk introduces 34Mb Serial NOR Flash—first MLc flash chip for SSD applications
SanDisk changes name to SanDisk
Flash (NOR and NAND) revenues exceed $1B
CompactFlash Association (CFA) founded
SanDisk introduces the first flash cards with MLC serial NOR
Palm introduces flash memory-based PDA
0.35 micron process announced
$2.68 in flash memory revenues, 163,663% growth in 10 years
Lexar Media spins off from Cirrus Logic
USB Association (USBA) founded

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<table>
<thead>
<tr>
<th>Year</th>
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<th>Event</th>
</tr>
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<tbody>
<tr>
<td>1997</td>
<td>2,701,678,000</td>
<td>SanDisk introduces flash-based MPMan MP3 player</td>
</tr>
<tr>
<td>1998</td>
<td>2,492,552,000</td>
<td>Toshiba and SanDisk create flash memory manufacturing joint venture</td>
</tr>
<tr>
<td>1999</td>
<td>4,560,493,000</td>
<td>M-Systems introduces USB flash drives</td>
</tr>
<tr>
<td>2000</td>
<td>10,637,231,000</td>
<td>Intel ships its one-billionth flash unit</td>
</tr>
<tr>
<td>2001</td>
<td>7,594,502,000</td>
<td>TOSHIBA and SanDisk announce 1Gb MLC NAND</td>
</tr>
<tr>
<td>2002</td>
<td>7,766,797,000</td>
<td>Olympus and Fujifilm introduce t-Picture Card</td>
</tr>
<tr>
<td>2003</td>
<td>11,739,282,000</td>
<td>SanDisk introduces miniSD card</td>
</tr>
<tr>
<td>2004</td>
<td>15,610,575,000</td>
<td>U3 software system for USB flash drives introduced by SanDisk and M-Systems</td>
</tr>
</tbody>
</table>

Other notable events:
- 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 wafer begins production
- 500 million flash chips ship
- Intel introduces 2-bit/cell 64Mb MLC StrataFlash
- MultiMediaCard (MMC) unveiled by SanDisk and Siemens
- 130nm process announced
- 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
- 100nm process announced
- Toshiba and SanDisk jointly introduce Memory Stick PRO Micro
- 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 Microform flash joint venture
- Hynix NAND product introduced
- Infineon NAND product introduced based on Saffun Charge Trap Flash
- Panasonic and Sony introduce first flash-based camcorders
- SanDisk introduces Flash Sansa MP3 players
- Freescale (later EverSpin) ships first commercial MRAM NVM
<table>
<thead>
<tr>
<th>Year</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sales ($ million)</td>
<td>18,568,940,000</td>
<td>20,076,313,000</td>
<td>22,182,405,000</td>
<td>18,435,970,000</td>
<td>19,302,693,000</td>
<td>26,734,247,000</td>
<td>28,123,615,000</td>
<td>28,213,759,000</td>
</tr>
</tbody>
</table>

**2020 Flash Memory Timeline**

- **2005**
  - Apple introduces first two flash-based iPods (iPod shuffle and iPod nano)
  - Microsoft introduces Hybrid Hard Disk Drive concept
  - MMC/micro 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

- **2006**
  - 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 Gruentech
  - SanDisk 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
  - Open NAND Flash Interface (ONFI) v1.0 spec published
  - Numonyx and Samsung introduce phase change NVM

- **2007**
  - 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 iDrive MLC NAND-based PCIe X4 board
  - BITMICRO launches 3.5 SSD with capacity of 1.6TB (for military applications)
  - Spansion acquires Safuron
  - 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
  - NVM revenues exceed $14.5B
  - Flash revenues exceed $22B, almost 9 times 1997 revenues
  - Seagate announces Hybrid Storage Alliance
  - Seagate introduces first hybrid HDD, the Momentum PSD
  - MMCA/JEDEC eMMC spec published

- **2008**
  - SanDisk introduces ABL to enable high speed MLC, TLC and X4 NAND
  - 54nm 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 Memory introduces first fully flash-based storage appliance
  - Samsung announces 160GB 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
  - HGST releases first SSD with a SAS interface
  - Intel and Micron introduce 34nm TLC NAND
  - Samsung introduces first full HD camcorder with 64GB SSD
  - Seagate enters SSD market
  - SanDisk redefines first compression-based SSD controller
  - Intel 7nm NAND flash
  - Intel and Micron introduce first self-managed hybrid HDD
  - Hybrid Storage Alliance founded
  - JEDEC publishes two specs for Solid-State Drives: “SSD Requirements and Endurance Test Method” and “SSD Endurance Workloads”

- **2009**
  - Toshiba introduces 128GB SD card based on 16-chip stack
  - Intel, Micron introduce 25nm TLC and MLC NAND
  - Numonyx acquired by Micron
  - Micron acquires SST and 3-bit MLC NAND
  - SanDisk introduces ABL approach to enable high speed MLC, TLC, and X4 NAND
  - 54nm process announced by Intel and Micron
  - Toshiba introduces first 512GB MLC SATA-based SSD
  - Intel and STMicro spin off Numonyx
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- **2010**
  - LSI acquires SandForce
  - SanDisk acquires Plant
  - IMFT introduces 20nm NAND flash
  - Intel announces Smart Response SSD caching for PCs
  - Seagate enters NAND business
  - 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
  - MOS60 samples 333GHz HL-NAND
  - Adesto acquires ATMEG’s Serial NOR business
  - Spannoc introduces 8Gb NOR chip
  - DeniBit Technologies introduces Memory Modem
  - Proximal Data introduces AutoCache
  - SanDisk acquires FlashSoft
  - EMC acquires XtremIO
  - OCZ acquires Sandisk
  - Samsung acquires NVxL0cel
  - Intel acquires Nveox and introduces CacheWorks
  - LSI introduces Nytro flash with MegaRAID CacheCode caching software
  - Micron introduces 2.5” PCIe enterprise SSD
  - IBM acquires Texas Memory Systems
  - Cypress Semiconductor acquires Ramtron
  - Western Digital acquires HGST
  - Skyera launches 4TB flash array
  - JEDEC and ONFI introduce Toggle mode
  - SanDisk founder Eli Harari receives FMS Lifetime Achievement Award

- **2011**
  - SanDisk and Toshiba announce 20nm process in 128Gb chips
  - Ultrabooks begin to ship with Smart Response SSD cache
  - Macronix and Winbond enter NAND business
  - Seagate enters SSD business
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