Flash memory talk
Felton Linux Group
27 August 2016
Jim Warner
Flash Memory Summit

Annual trade show at Santa Clara Convention Center

Where there is money, trade shows follow.

August 8 – 11, 2016
Borrowing liberally from . . .
Industry analysts
SSD

- Flash memory is [now] component to make solid state disks
- Bits stored as charge in conductive regions surrounded by an insulator.
- Electric field from the stored charges is detected by a nearby field effect transistor
Remember?

- UV Eraseable EPROMs?
- These were the first devices to use isolated charge regions for computer storage.
How flash works . . .

“Each NAND flash memory cell is a floating gate transistor whose threshold voltage can be configured (or programmed) by injecting certain amount of charges into the floating gate.”

Yangyang Pan, Guiqiang Dong, and Tong Zhang
Fowler-Nordheim tunnel
Two kinds . . .

<table>
<thead>
<tr>
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<th>NOR</th>
<th>NAND</th>
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<tbody>
<tr>
<td><strong>Cell Array</strong></td>
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<td><strong>Layout</strong></td>
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<td><strong>Cross section</strong></td>
<td>10F^2</td>
<td>4F^2</td>
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Bits per cell

- **SLC** - Enterprise class flash stores a single bit in each cell.
- **MLC** - Density can be increased by storing two bits in each cell. This is done by detecting four discrete charge levels.
- Apple music players made MLC popular.
- Devices are now available that store 3 bits per cell.
Wear out

- **Not** holes in the tunnel insulator
- High voltages during P/E cycles cause electrons to be trapped in insulating regions near the floating gate.
- These charges affect the transistor threshold adding noise to the read thresholds
- Rogue charges cannot be erased
NAND flash is doing well . . .

NAND Revenues 2006-2015

Annual Revenues ($Billions)


Objective Analysis – www.Objective-Analysis.com
NOR flash, not so much
Memory prices...
That is a factor of 1000 in twenty years. The flat spots are interesting . . .
Long term trends

- *Cost per Gigabyte* drops by 30 percent a year
- Now at about $0.33 per GB
- *Gigabytes produced* increase by 50 percent a year
- Q: When will flash pass magnetic disk?
- A: Don't hold your breath.
Comparison w Disk

- Magnetic disk sectors can be re-used by writing over the contents. No preparation for re-use is required.
- Flash memory needs to be cleared to an all 1's state. Then new content can be written to it.
- The clear operation takes longer than either reading or writing.
- As a background task, released sectors are erased.
Comparison [more]

- Putting released blocks through an erase cycle is a form of garbage collection.
- The electronics that manages the flash is unaware of file system semantics that make blocks claimed or free.
- The *Fix* is for the OS to provide a list of blocks to be erased. The SATA TRIM command implements this. Rick Moen says kernels 3.8 and beyond do this right.
Comparison [more]

- Disk defragmentation was a good thing to do with your spinning disk. It improved speed by increasing the size of chunks of files that were stored contiguously.
- *Defrag* is unnecessary for SSDs because latency does not depend on location.
- Defrag would increase the rate of erase operations and shorten the life of the flash.
Formats

- SSDs can be packaged with electronics that makes them appear as SATA drives – but much faster because there is no rotational and seek latency.
- SSDs can also have SAS [Serial Attached SCSI] interfaces to get higher data rates.
- Neither of these match the speed of the devices. High performance SSDs connect directly to PCIe slots.
NVMe

- = **Non Volatile Memory express**
- PCIe standard is not enough
- Need API with common command set to manage flash functions
Why are SSDs a good idea?

Market Dynamics

Flash ROI vs. HDD

- Power: -73%
- Cooling BTU: -73%
- Floor Space (CU FT): -88%
- Maintenance: -84%

Source: Solid-State Array TCO Reality Check, published 22 January 2016
SSD is also 5x faster
Rotational latency

- Spinning disk latency determined by rotational speed.
- The high performance end of the disk drive market – 10,000 RPM and 15,000 RPM
- These are dead products; this market now dominated by flash.
- Spinning disk has a cost-per-byte advantage using 7200 RPM drives.
- Laptops use 5400 RPM drives.
3D Flash

Next big thing will be 3D Flash. This is what it sounds like – layers of flash on the silicon substrate.

3D flash is available now, but it costs more to make than 2D flash. This is [we hope] a temporary problem.
3D architecture

[Diagram of 3D NAND Architecture with labels SGD, WL, SGS, Bit Line, BL Contact, Memory Holes, Source Plate, Memory Cell]
3D Trouble spots

- High aspect ratio trenches
- Deposition of tens of layers
- No doping on source or drain
- Perfectly parallel walls
- Tens of stairsteps
- Uniform layer across wafer
- Single-litho stairstep
- Hard mask etching
- Processing inside of hole
- Etch through varying materials
- Charge trap storage
- Polysilicon channels
- Deposition on hole sides
3D Predictions

• The industry always says *Next Year*
• Manufacturers are either producing product [Samsung] or making samples, so good signs.
• Jim Handy says 2018
• 3D will create a capacity glut
• Expect prices to collapse til demand catches up
What's next??

- Storing bits as insulated charge is about 30 years old
- Bits can be remembered in phase state changes.
- Intel/Micron are sampling Xpoint memory in the 1-10 uS speed region. Not clear what it is.
- Intel needs this and may sell at a loss to get it.
- Otherwise, needs to be cheaper than DRAM
THANKS !