ECE590-03
Enterprise Storage Architecture

Fall 2016

Survey of Next-Generation Storage

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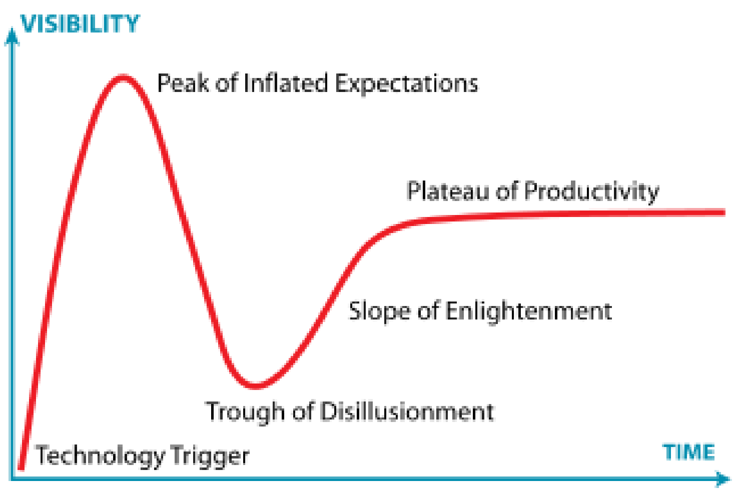
Lots of possible avenues...

- Wikipedia "list of emerging technologies" for storage:

Emerging technology	Status	Potentially marginalized technologies	Related articles
Emerging memory technologies	In development	Current memory technologies	T-RAM, memristor, Z-RAM, TTRAM, CBRAM, SONOS, RRAM, Racetrack memory, NRAM, Phase-change memory, FJG RAM, Millipede memory, Skyrmion, Programmable metallization cell, 3D XPoint, Ferroelectric RAM, Magnetoresistive random-access memory, nvSRAM
Emerging magnetic data storage technologies	In development (HAMR, BPM); diffusion (SMR)		SMR, HAMR, BPM, MAMR, TDMR, CPP/GMR, PMR, Hard disk drive

- That's a lot of things! Most won't pan out
- Temper your excitement, remember the hype cycle...



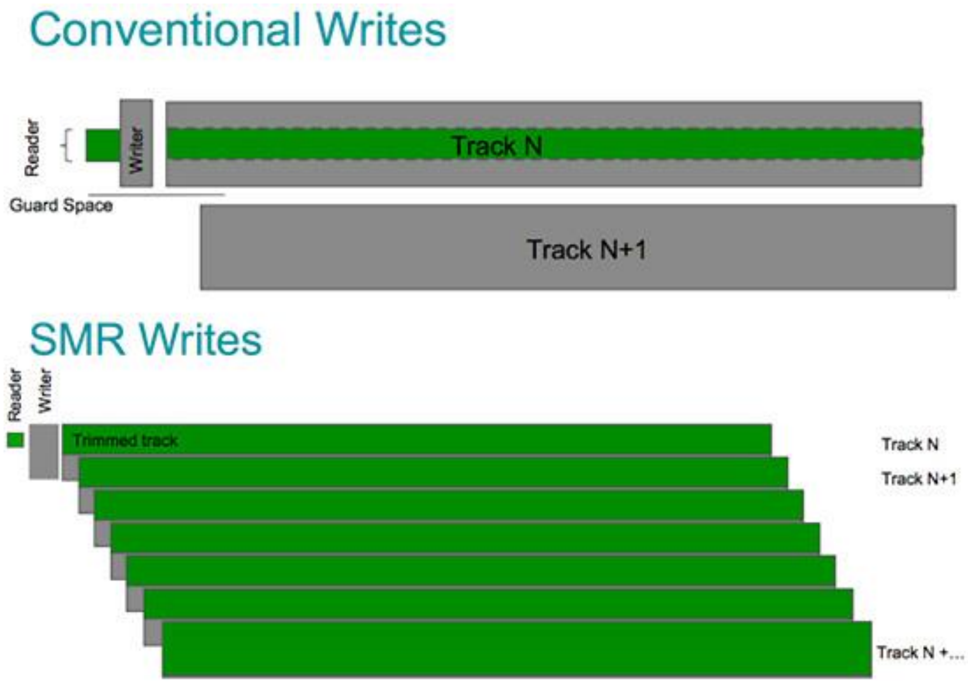
Areas of focus

- Improving HDDs
  - Shingled magnetic recording (SMR)
  - Heat-assisted magnetic recording (HAMR)
  - Bit-patterned media (BPM)
  - Just pump a bunch of helium into there
- Improving SSDs
  - 3D NAND structures
- New solid-state memories
  - Phase-change memory (PCM)
  - Ferroelectric RAM (FRAM)
  - Magnetoresistive RAM (MRAM)
  - Resistive RAM (RRAM)
  - Conductive Bridging RAM (CBRAM)
- Memristors: are they a thing?
- Theoretical and proof-of-concept stuff

Improving HDDs

Shingled magnetic recording (SMR)

- Due to physics reasons, the write head is always bigger than the read head
  - This means that we write a track of X width, but we just read the middle X/2 of it back.
  - Tracks aren't allowed to overlap, so this leads to waste
- Solution: let them overlap, and deal with resulting destruction



Feasible? **Yes.** Seagate started shipping in 2013.

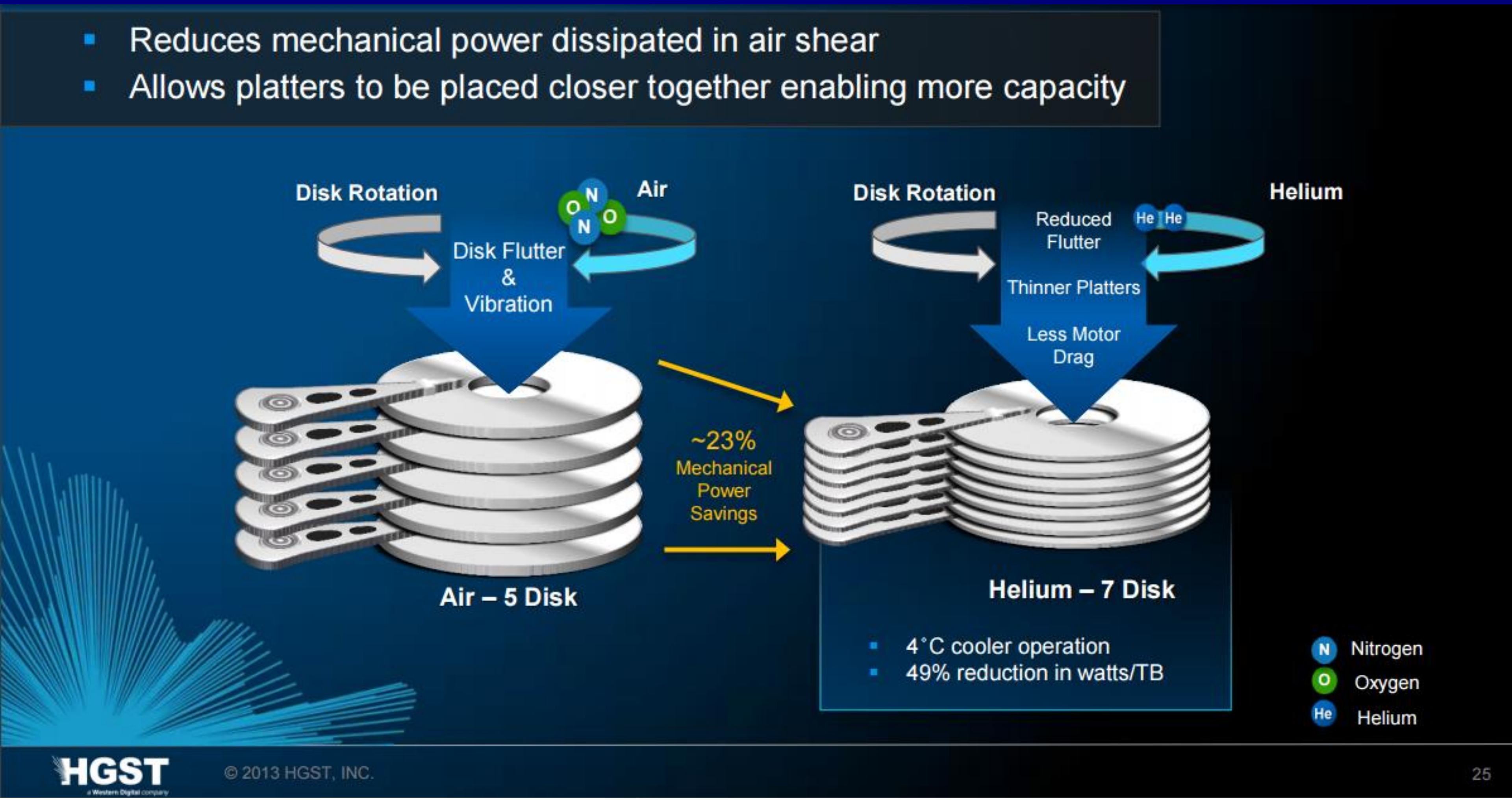
Diagram source.

Shingled magnetic recording (SMR)

- Dealing with overlap
  - Drive reads neighboring data under threat from a pending write; restores it afterward.
  - If we blindly do that to whole drive, then single write means rewriting whole drive...
  - Solution: Do SMR on track groups.
  - Wow! HDD now like SSD: Small read sectors, big erasure blocks!
  - Lots of cache and optimization opportunities...

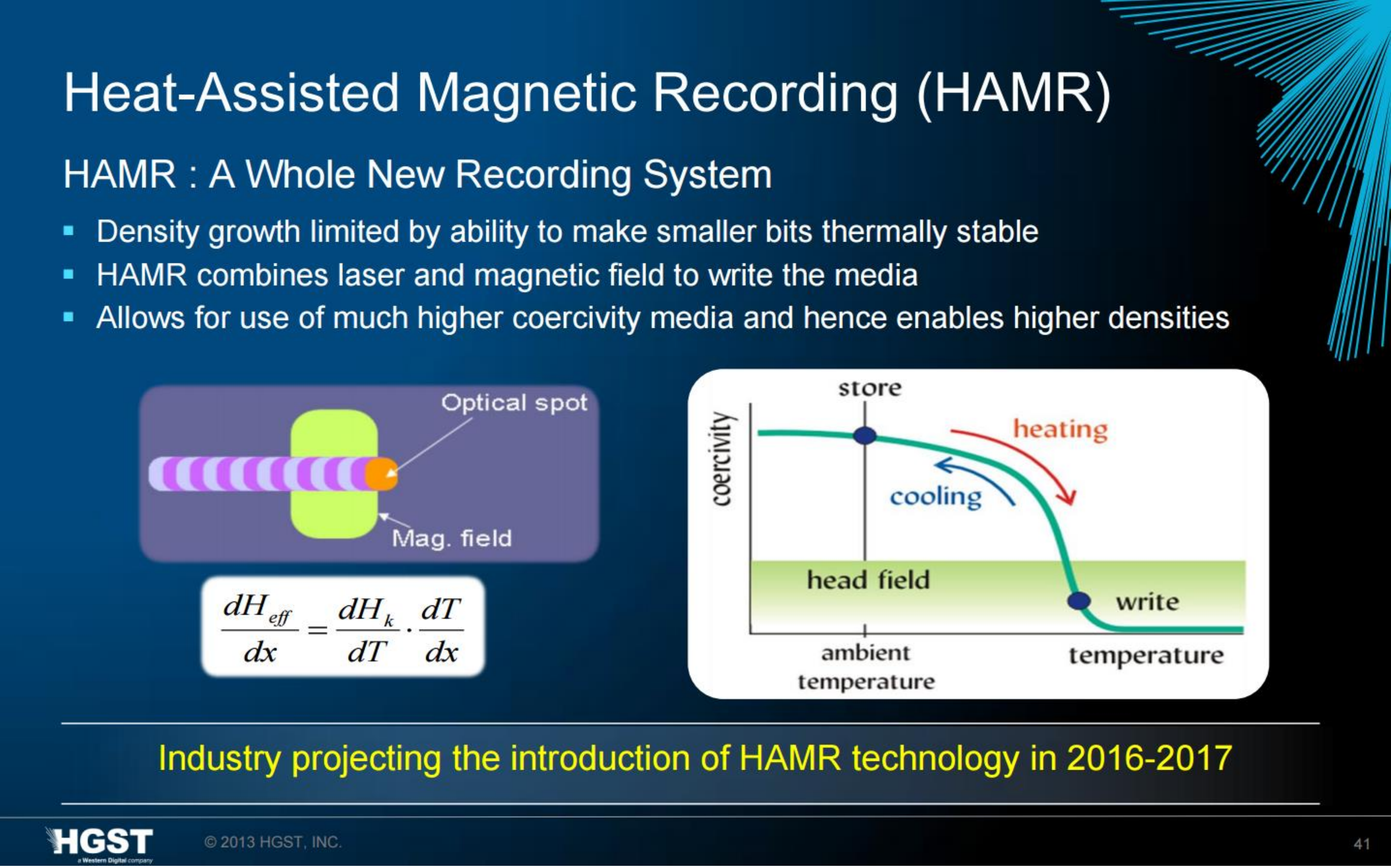
Feasible? Yes. Seagate started shipping in 2013.

Seal the HDD and fill with helium



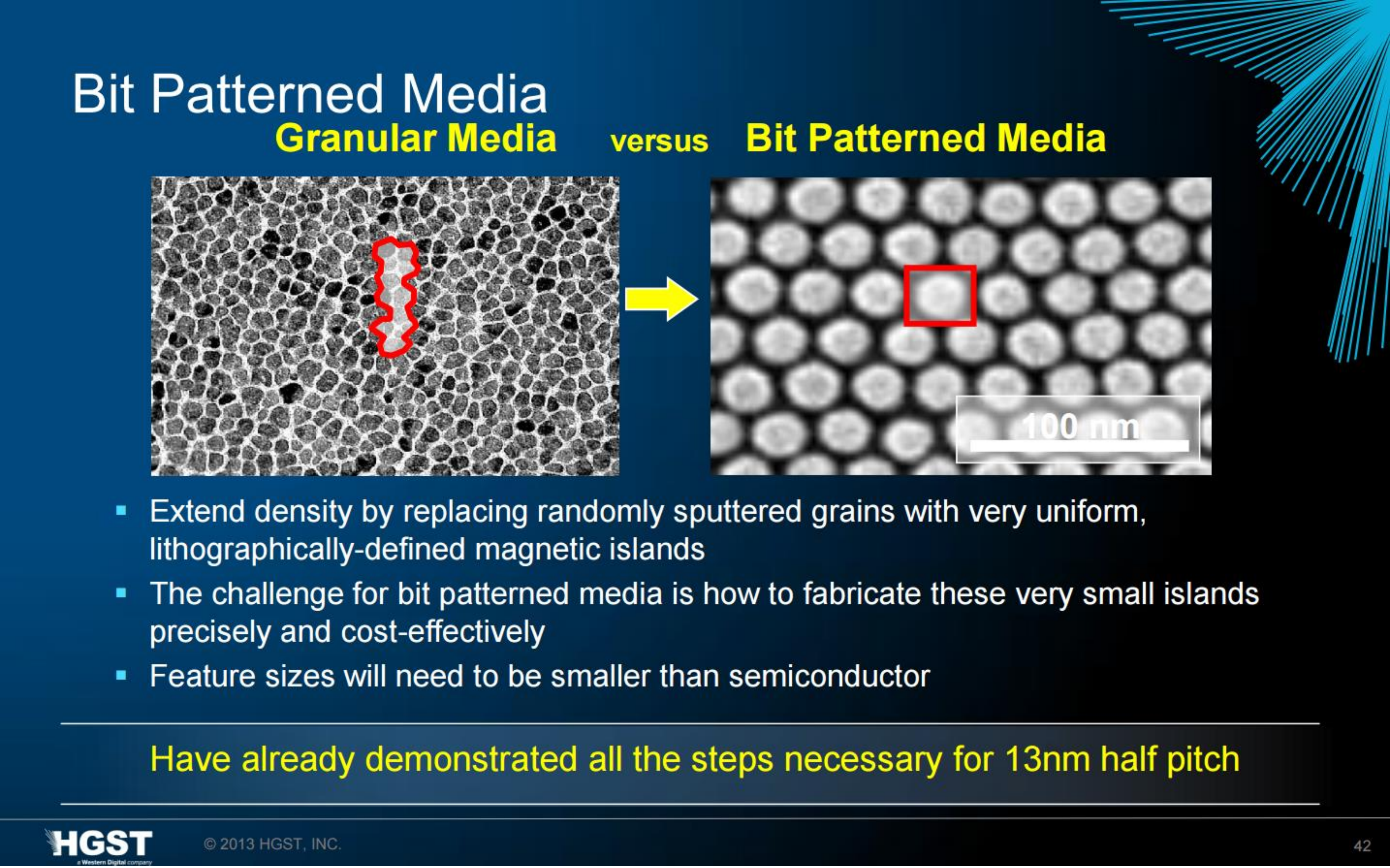
From “Navigating Storage in a Cloudy Environment” by Steve Campbell, HGST.

Feasible? Yes. HGST started shipping in 2013.



From "Navigating Storage in a Cloudy Environment" by Steve Campbell, HGST.

Feasible? Fairly likely. Seagate has prototypes (src). Latest estimates are 2018 (src).



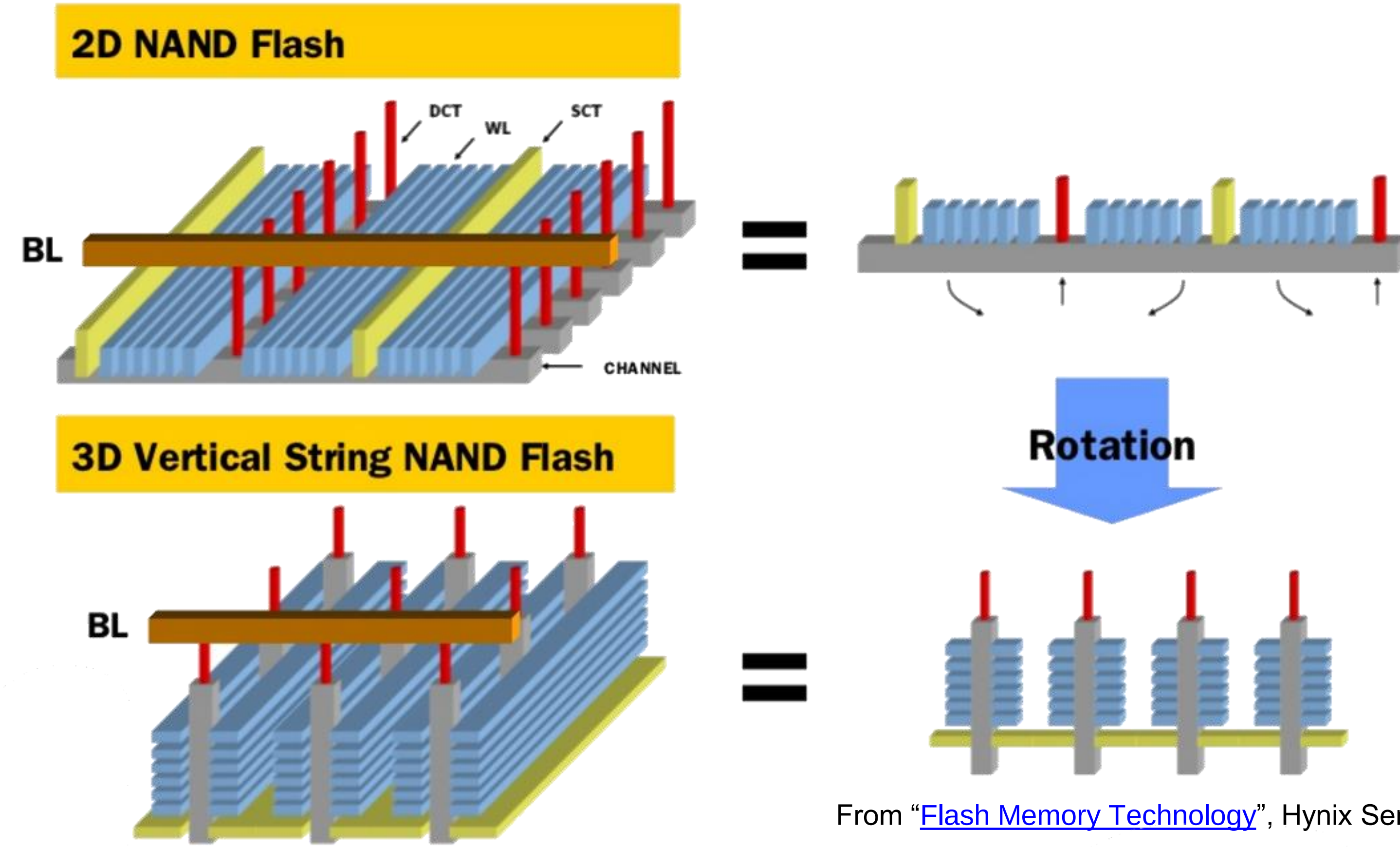
From "Navigating Storage in a Cloudy Environment" by Steve Campbell, HGST.

Feasible? Somewhat likely. HGST has proved the lithography, but there are lots of problems still left (src).

Improving SSDs

3D NAND structures

- Current SSD/flash design: NAND gates laid out in 2D



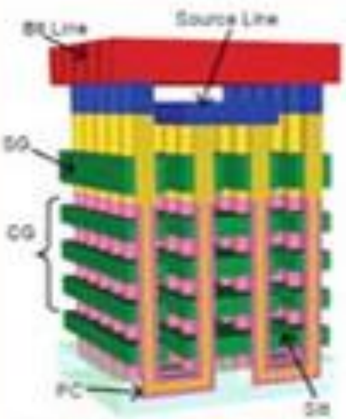
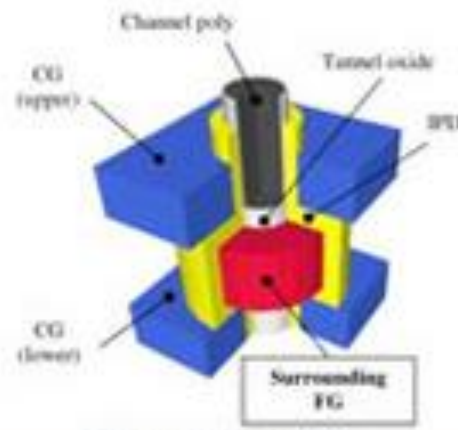
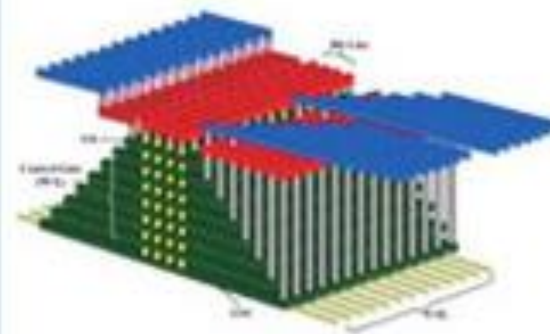
From “[Flash Memory Technology](#)”, Hynix Semiconductor.

- Novel idea: Make it 3D. Lots of ways to do this...

Feasible? **Yes.** Intel/Micron have chips shipping. ([src](#))

3D NAND structures

- Lots of ways to do this...

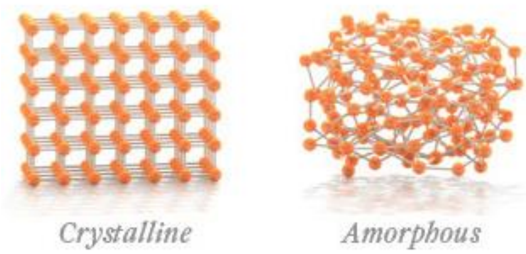
	Toshiba/P-BICS	Hynix DC-SF	Samsung/TCAT
Type of 3D NAND	 R. Katsumata et al, VLSI 2009	 S Whang et al, IEDM 2010	 J. Jang et al, VLSI 2009
Transistor	Gate all around; Salicided Poly Si gate	Gate all around; Salicided Poly Si gate	Gate all around; Damascene metal gate
Storage	Charge trap	Floating gate	Charge trap

From "3D NAND Approaches", IMW 2011. [Figure from here](#).

Feasible? Yes. Intel/Micron have chips shipping. ([src](#))

New solid state memories

Phase-change memory (PCM)



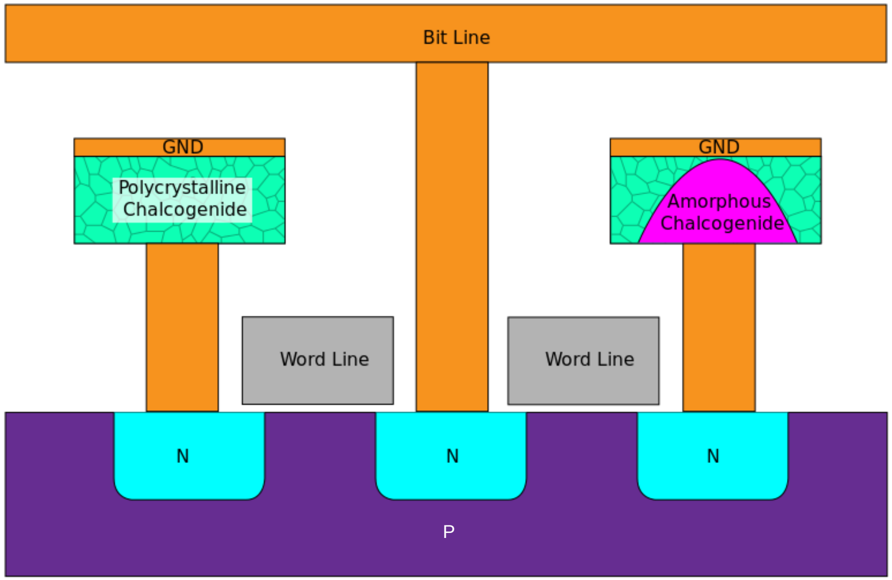
Low Ω   High Ω

- Fundamental enabler: Chalcogenide glass
  - A glass compound with sulfur, selenium, or other additive
  - Rate of heating/cooling can produce **amorphous** or **crystalline** structure
  - Two structures behave very differently optically and electrically
- This is what makes re-writable CD/DVDs possible
- To "write":
  - Melt with brief, hot pulse of heat; rapid cooling gives amorphous state
  - Melt with long, low-intensity heat; slow cooling gives crystalline state
- To "read":
  - Crystalline is low resistance, amorphous is high resistance
  - Measure resistance with circuit, decide which one means "1"

Feasible? Technically, yes; economically, maybe...

Phase-change memory (PCM)

- Array these elements in a grid like any other RAM
- Use electricity to heat cells (write) and to determine their resistance (read)



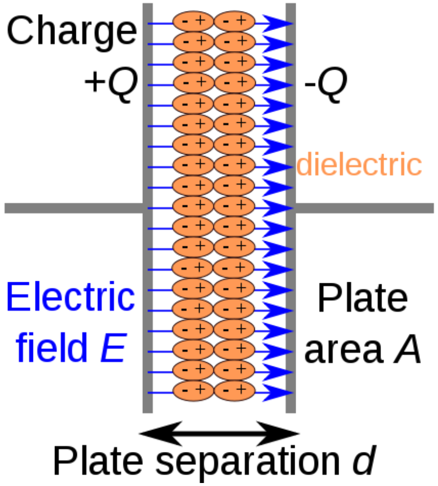
"A cross-section of two PRAM memory cells. One cell is in low resistance crystalline state, the other in high resistance amorphous state."
From Wikipedia, "Phase-change memory"

Feasible? Technically, yes; economically, maybe.

- Shipping memory chips available from many vendors
- Large-scale adoption hasn't happened; flash still wins for most use cases when you factor in cost
- Roller-coaster development history:
  - In 2012, Micron announced PCM for mobile devices (src)
  - In 2014, flash had gotten better (e.g. 3D NAND), and Micron ditched PCM! (src)
  - In 2015, PCM appeared dead, but then Western Digital showed a PCM prototype with 3 million IOPS (src)
  - Intel/Micron's "3D Xpoint memory" is a PCM released in 2016 (src)

Ferroelectric RAM (FRAM)

- Like DRAM, but uses a "**ferroelectric**" layer instead of the DRAM capacitors' dielelectric.
- Ferroelectric material: Material that has an electric polarization which can be flipped
  - Material consists of polarized molecules (one side positive, other side negative)
  - If you flip one molecule, attraction/repulsion resets it
    - Stable, self-correcting
  - Apply enough voltage, flip *all* molecules
    - Settable!



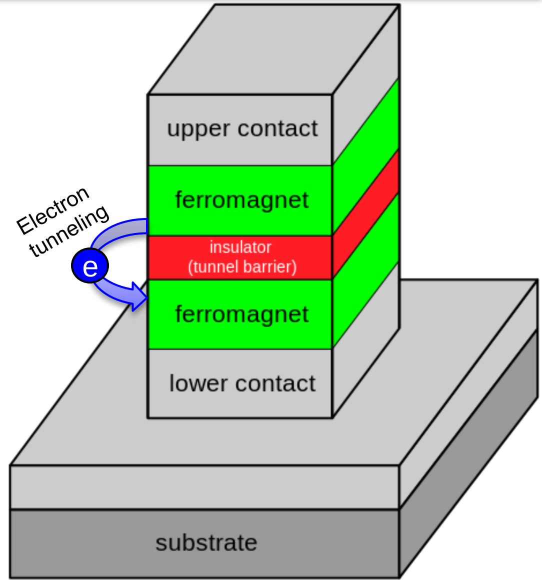
From Wikipedia, "Ferroelectric capacitor"

Feasible? Technically, yes; economically, maybe.

- Shipping memory chips available from vendors
- Large-scale adoption hasn't happened; seems unlikely under current trends
- Density isn't great (130nm), but lower power than flash
- Current niche: storage for very-low-power embedded systems

Magnetoresistive RAM (MRAM)

- Uses a “**ferromagnetic**” material
  - Metal that can change magnetic field to match an external field (e.g., normal iron)
- Exploits “**tunnel magnetoresistance**”
  - Due to wacky probabilistic quantum physics, an electron in the top layer can “tunnel” (randomly transposition to) the bottom layer
  - If both magnets have same polarity, this tunneling is much more likely (src)
  - Macroscopic effect: resistance is lower
- Can flip magnetic polarity with electrically-created field (write), determine polarity by measuring resistance (read)



From Wikipedia, “Tunnel magnetoresistance”

Feasible? **Technically, yes; economically, maybe.**

- Only one shipping commercial part (a 4Mbit chip from Everspin)
- Large-scale adoption hasn’t happened; seems uncertain
- Density is lousy (180nm), but great performance and lower power than FRAM
- Current niche: storage for very-low-power embedded systems
- Various rumors and promises of upcoming chips from larger vendors (...?)

Others

- Conductive bridging RAM (CBRAM): Electrochemical reaction changes resistivity of cells.
  - Development startup Adesto holds the intellectual property, limited products have been realized.

Feasible? Technically, yes; economically, unlikely?

- Resistive RAM (RRAM): Create/fill electron "vacancies" in a thin oxide layer; changes resistivity of cells.
  - Various small commercial chips exist in the kB range.

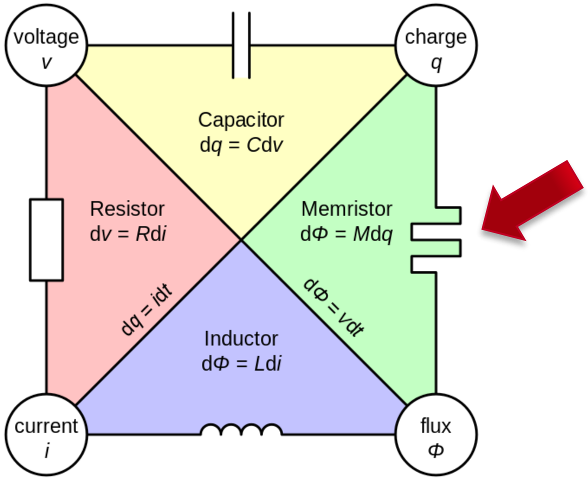
Feasible? Technically, yes; economically, unlikely?

- "Millipede memory": Create and fill microscopic holes in a thin polymer.
  - In 2005, IBM was aiming to have this out within 2 years, but other forms of storage advanced faster and wrecked it

Feasible? Technically, ???; economically, dead.

Memristors: are they a thing?

- Memristor: A theoretical circuit element that changes resistance based on past current
  - Existence was proposed by taxonomy in 1971:
    "If we have components that relate charge, voltage, current, and magnetic flux, shouldn't this thingy exist"? (src)

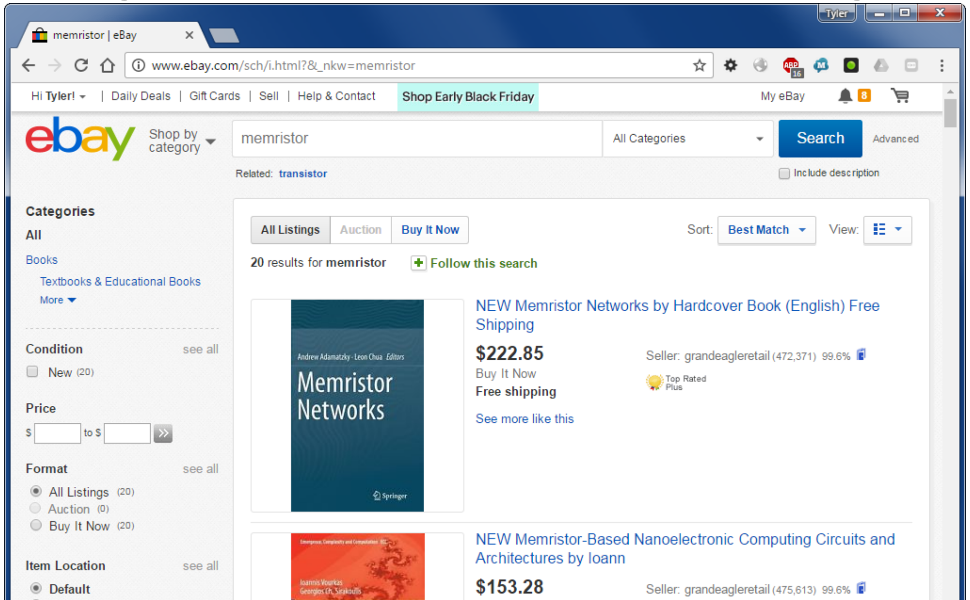


From Wikipedia, "Memristor"

  - By 2011 we didn't a good one, but we liked the name, so it changed to:
    "Any 2-terminal thing that changes resistance" (src)

Memristors: are they a thing?

- Problem: We just changed the definition so that it matches most of the proposed non-volatile RAMs we've discussed!
- Result: LOTS OF CONFUSION.
  - Technology press: ***"Memristors are the next big thing!"***
  - Actual semiconductor engineers working on this: "wtf are you talking about?"
- My opinion: "memristor" isn't a useful concept. Either:
  - It doesn't exist (original definition), or
  - It is achieved through a dozen different unrelated physical processes (new definition).
- The following shows that it's not a real thing:



Nothing but a few journals; no actual components to buy!

Speculative future stuff

AKA "A list of things that almost never pan out, except when they do"

Theoretical and proof-of-concept stuff

- Spintronics: Trying to do stuff with the quantum “spin” of electrons
- “Nano-RAM”: Storing data based on position of carbon nanotubes on a chip substrate
- Skyrmion: A hypothetical quantum particle related to magnetism
  - This is a literal sentence used to describe these:
    “A two-dimensional magnetic skyrmion, as a topological object, is formed, e.g., from a 3D effective-spin "hedgehog" (in the field of micromagnetics: out of a so-called "Bloch point" singularity of homotopy degree +1) by a stereographic projection, whereby the positive north-pole spin is mapped onto a far-off edge circle of a 2D-disk, while the negative south-pole spin is mapped onto the center of the disk.”
  - If that makes sense to you, invest in Skyrmion companies I guess?

Any of these feasible?
WHO KNOWS??

Theoretical and proof-of-concept stuff

- DNA: Yeah, we'll just encode data in DNA!
  - Ignore the fact that existing life doesn't do arbitrary writes operations on DNA (cells copy, viruses splice, meiosis mixes, and epigenetics alters attached methyl groups, but **nothing** makes arbitrary in-place changes)
  - Ignore that every aspect of DNA's evolution has been focused on protein synthesis, not specific "reads" of DNA locations
  - Ignore that even the fastest and most common IO pattern for DNA, copying during mitosis, takes on the order of hours, giving a data rate of around 60 kBps (similar to a dial-up modem)
  - No, DNA is the definitely the perfect way to store my pirated movies

Feasible? LOL