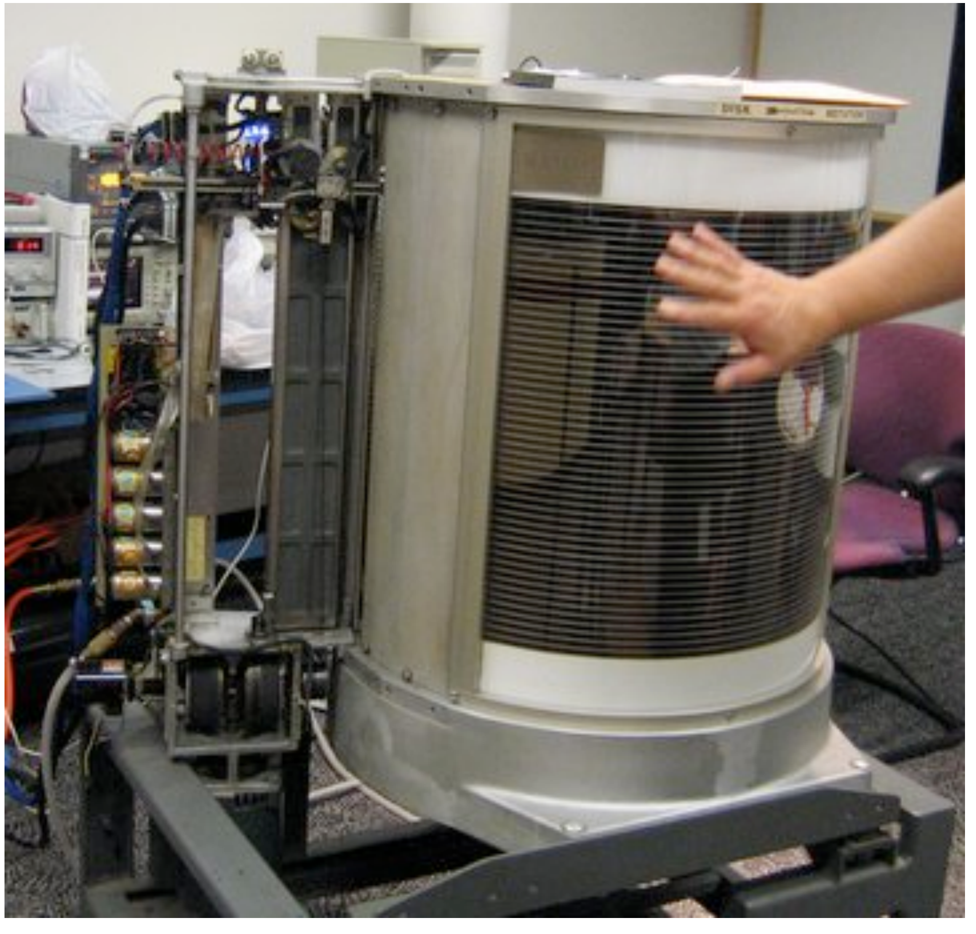
Project:
Your project will be to assess the prospects of a future information storage or memory technology.

Some possible technologies to consider (choose one):

Ferroelectric Random Access Memory
Optical Storage
Holographic Storage
Flash Memory
Phase Change Memory (PC-RAM)
Resistive Random Access Memory
Probe Based Storage Devices
Molecular Memory Devices

Introduction to Magnetic Recording



ph587

P. LeClair
26 Jan 2009

IBM 350 RAMAC, the first hard disk

it stored about 4.4Mb

wikipedia.org - “RAMAC”

what do I mean by magnetic recording?

what do I mean by magnetic recording?

what do I mean by magnetic recording?

hard disks.

only hard disks.

why do we use hard disks?

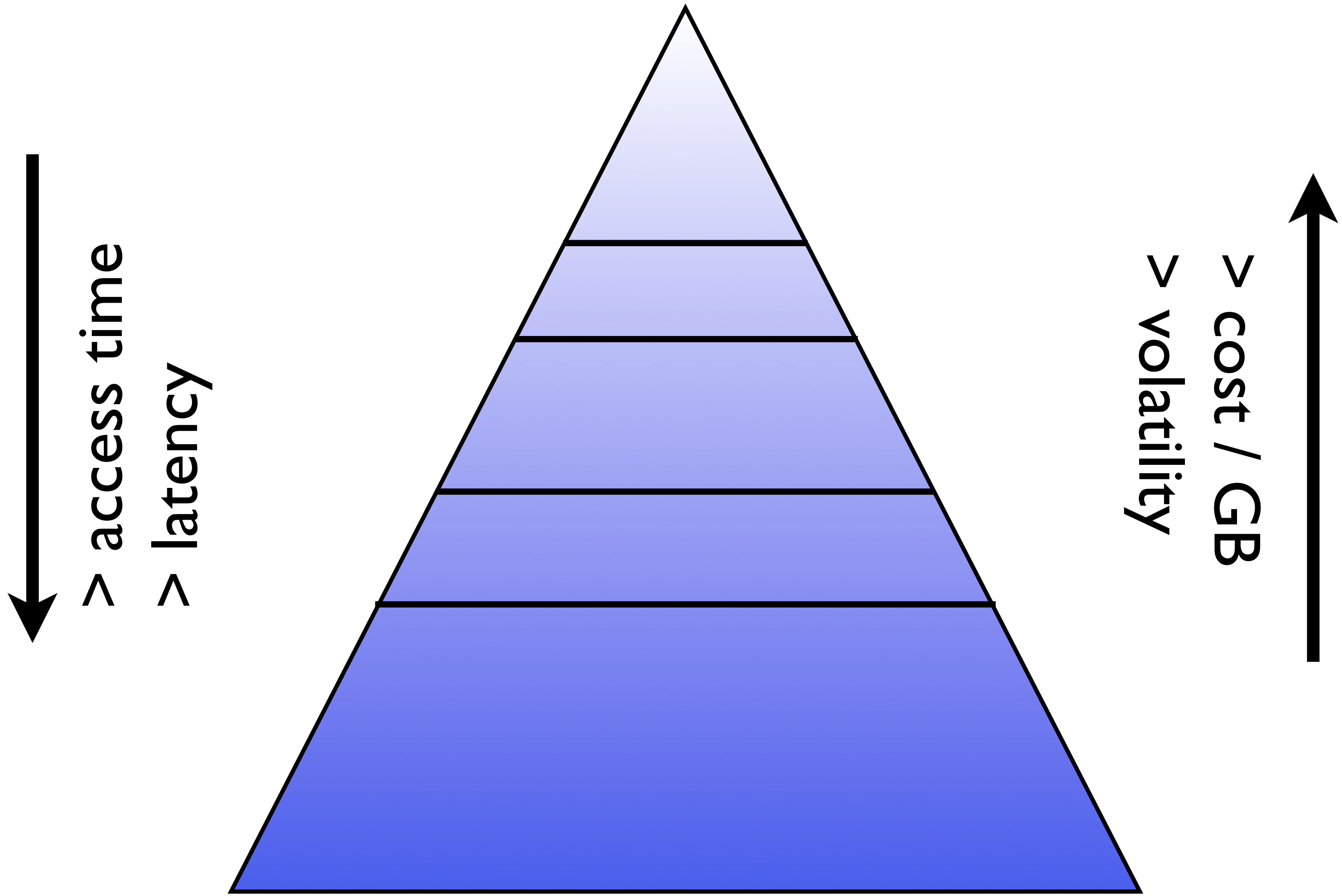
what is their role in a computer?

benefits?

disadvantages?

and the real reason .. $$$

basic PC architecture



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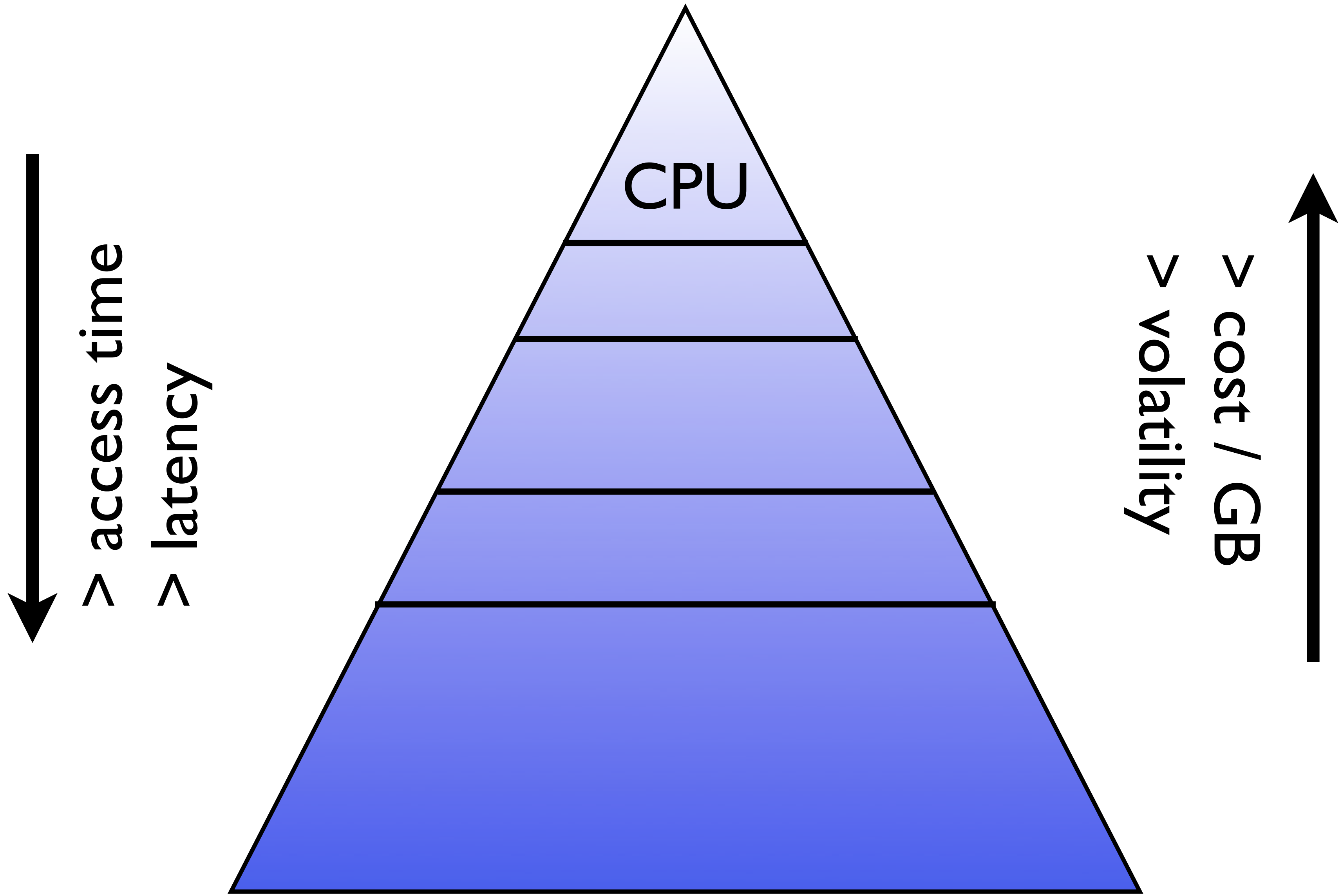

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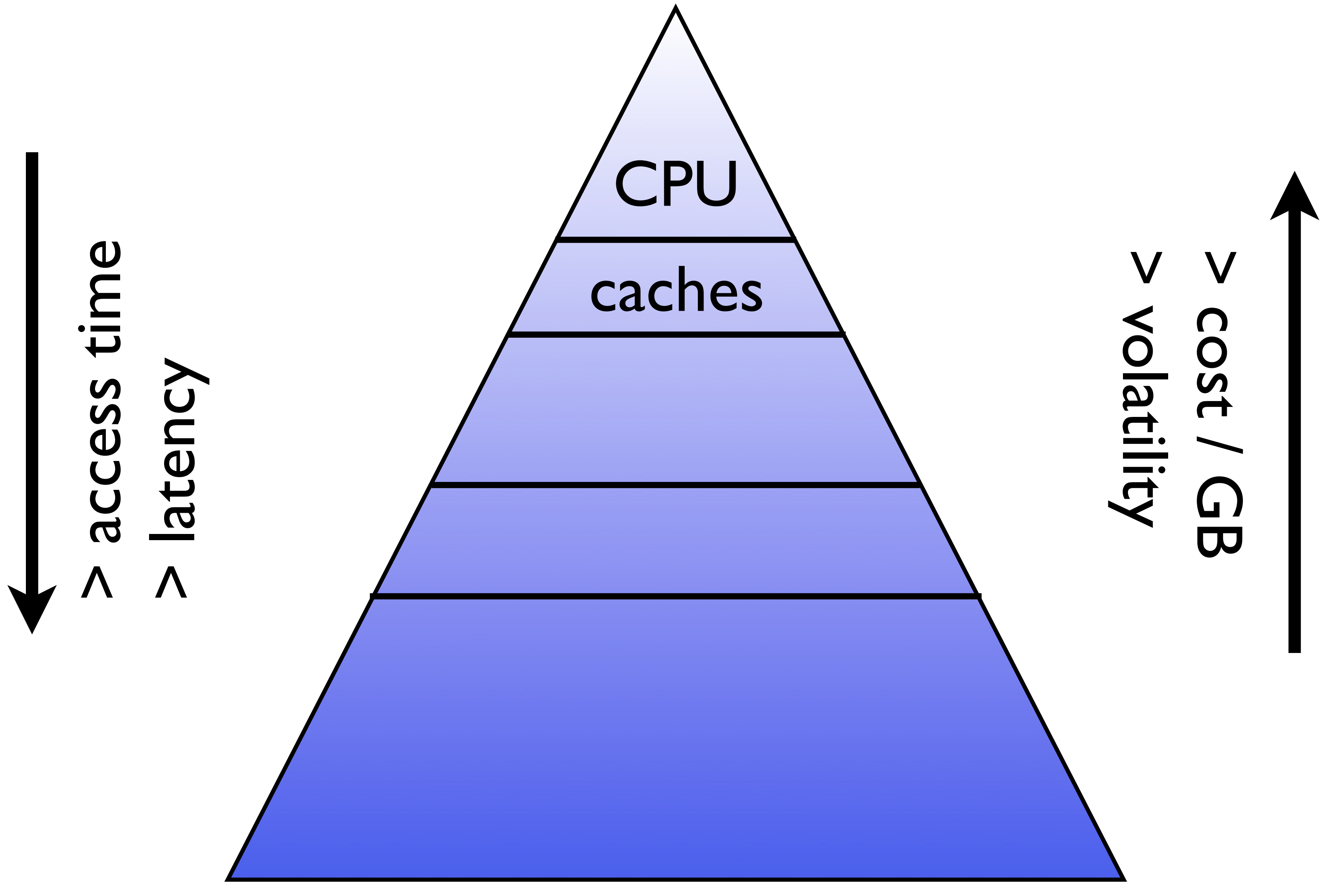

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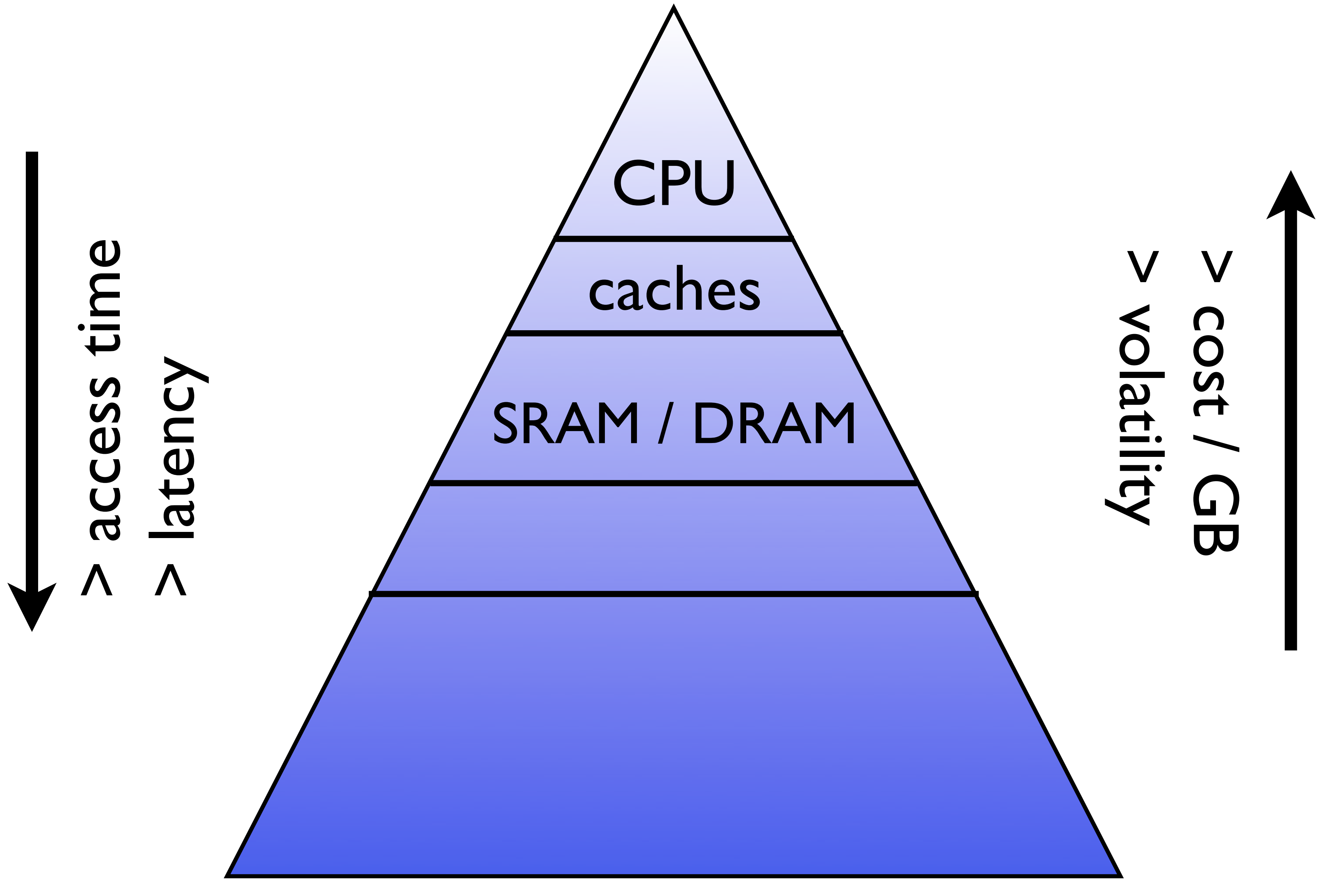

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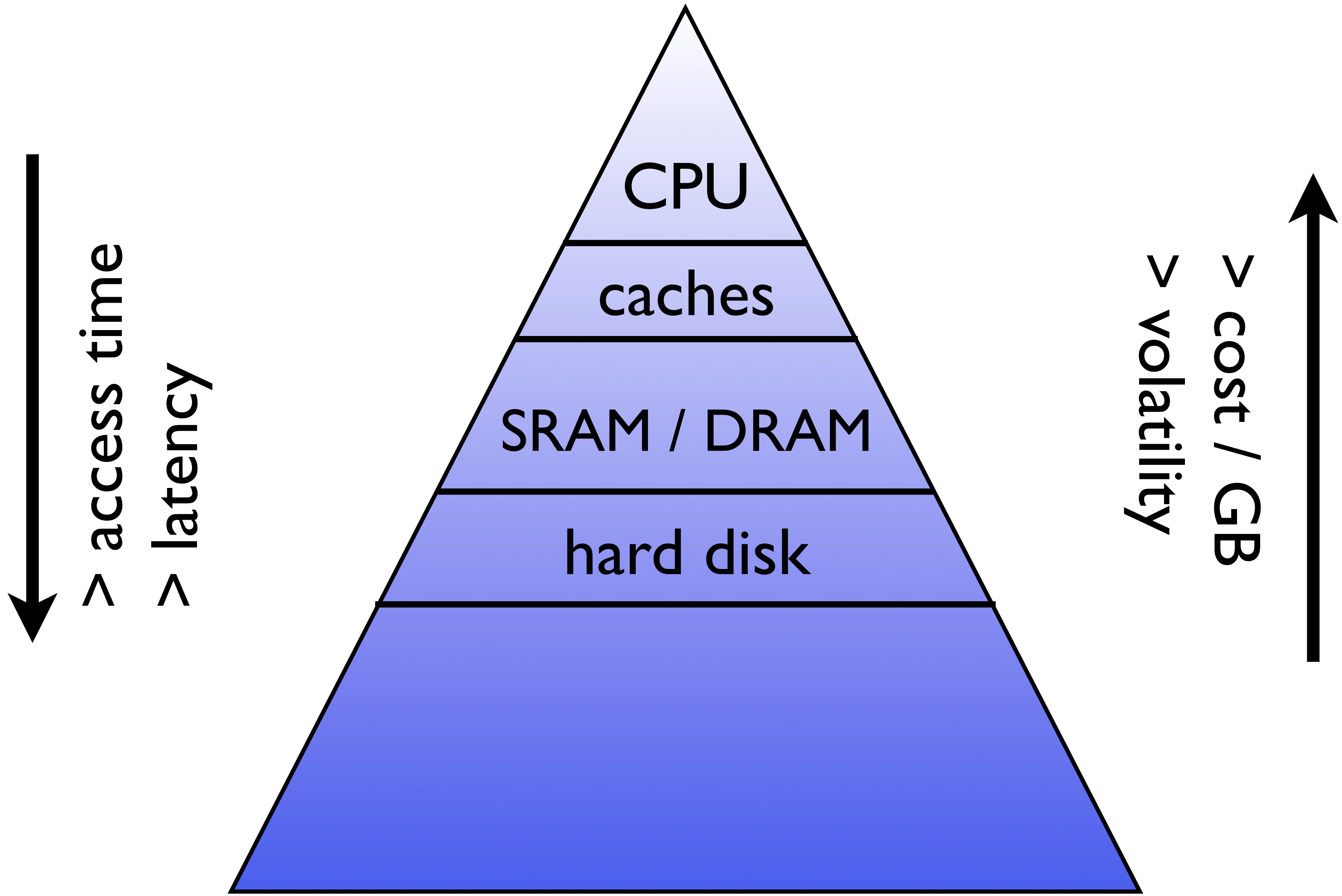

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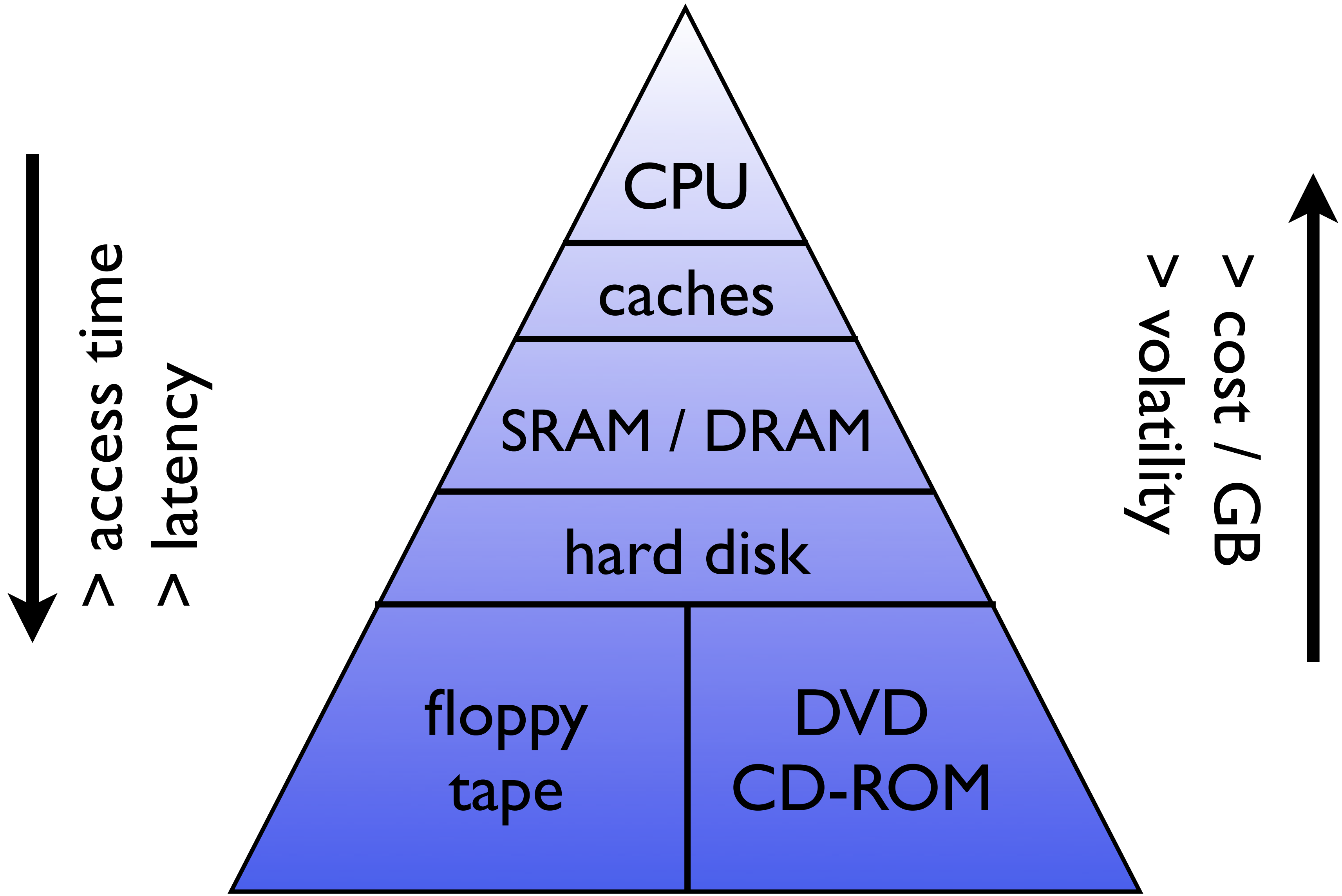

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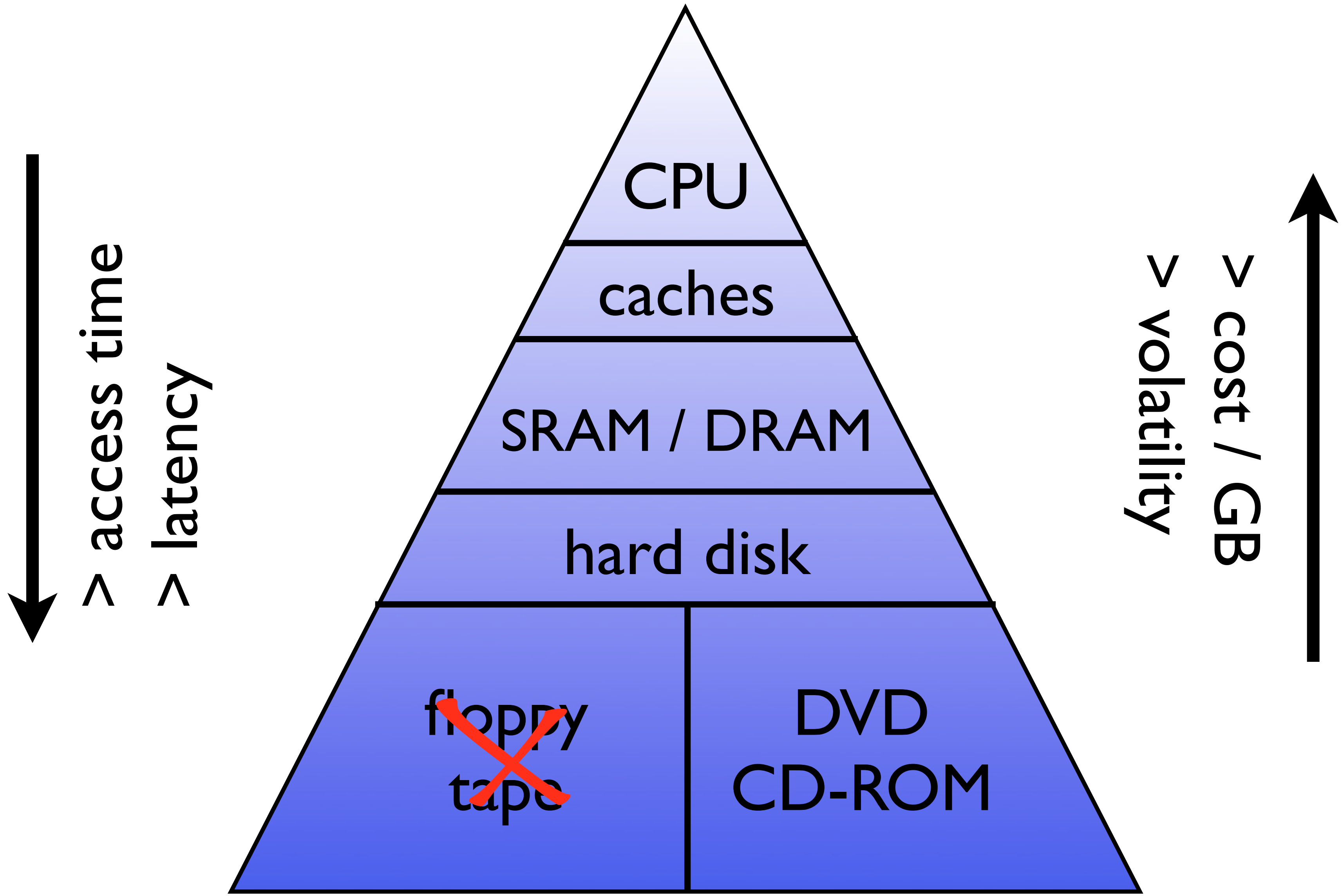

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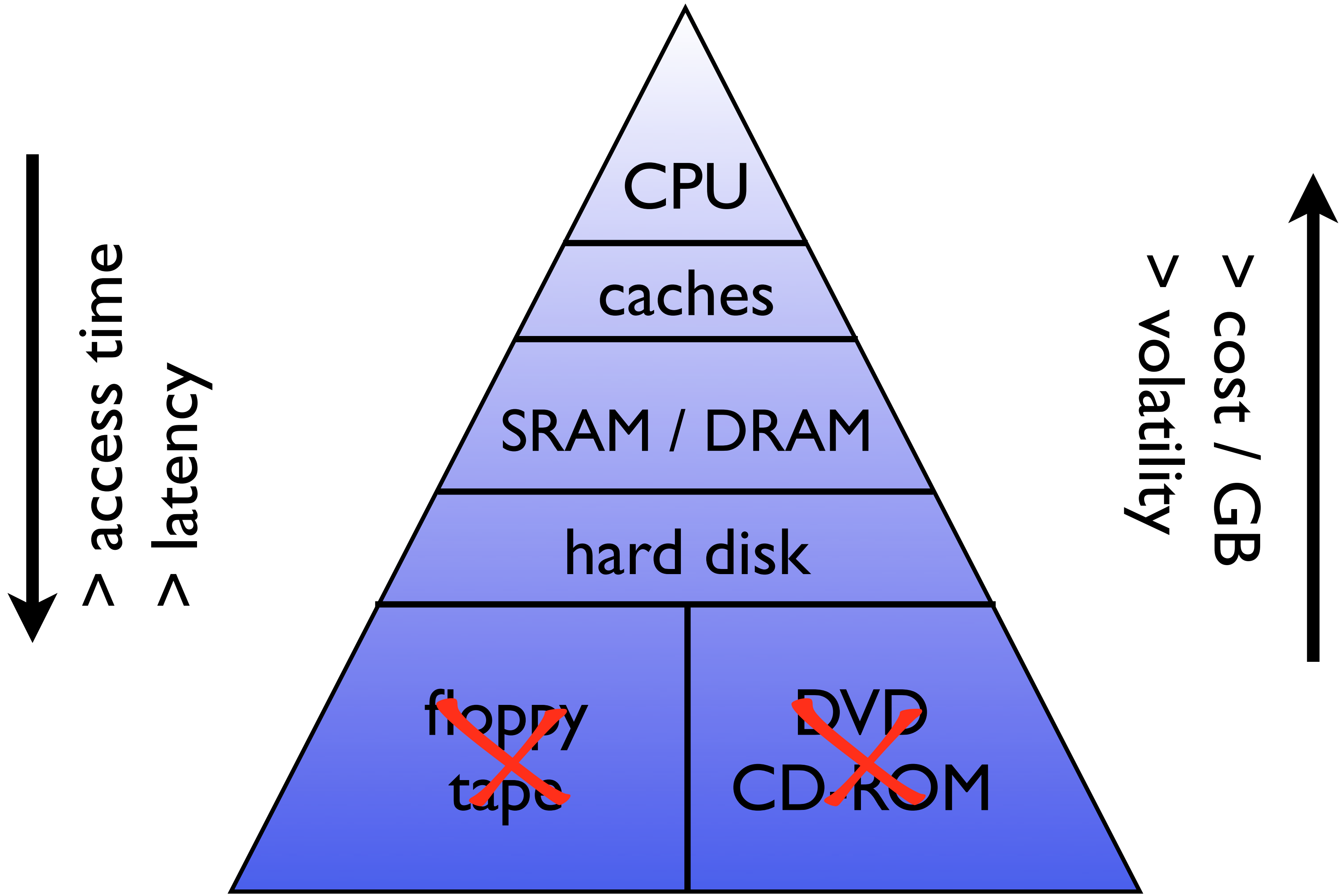


terminology

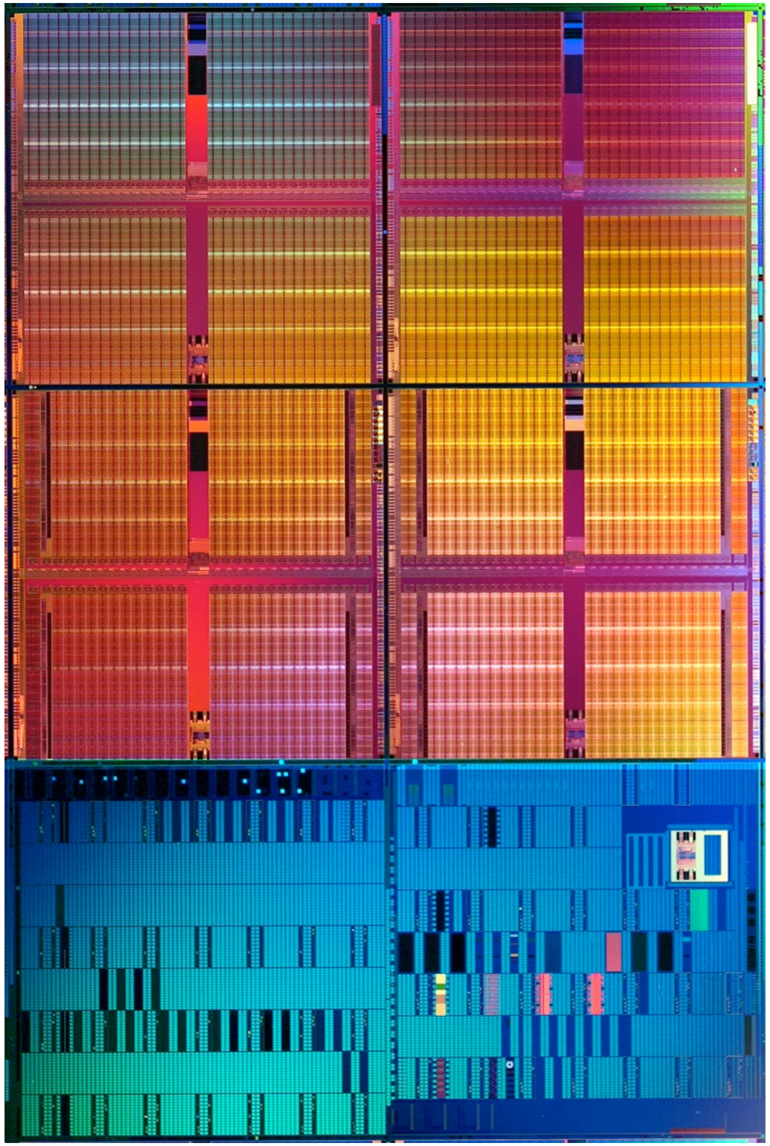
RAM
random access memory

ROM
read-only memory

access time & latency?
time between request for info & info returned

$ / GB
primary figure of merit.
most other things can be worked around

nonvolatility?
retains data without power



45nm SRAM die intel.com

every bit has a role

cache - *reduce latency to main memory*

small memories close to CPU

even faster than main memory

temp storage of frequently accessed items

SRAM / DRAM - *main memory*

blazingly fast

relatively large

voltaile!!

HDD - *mass storage*

higher latency

enormous capacity

nonvolatile

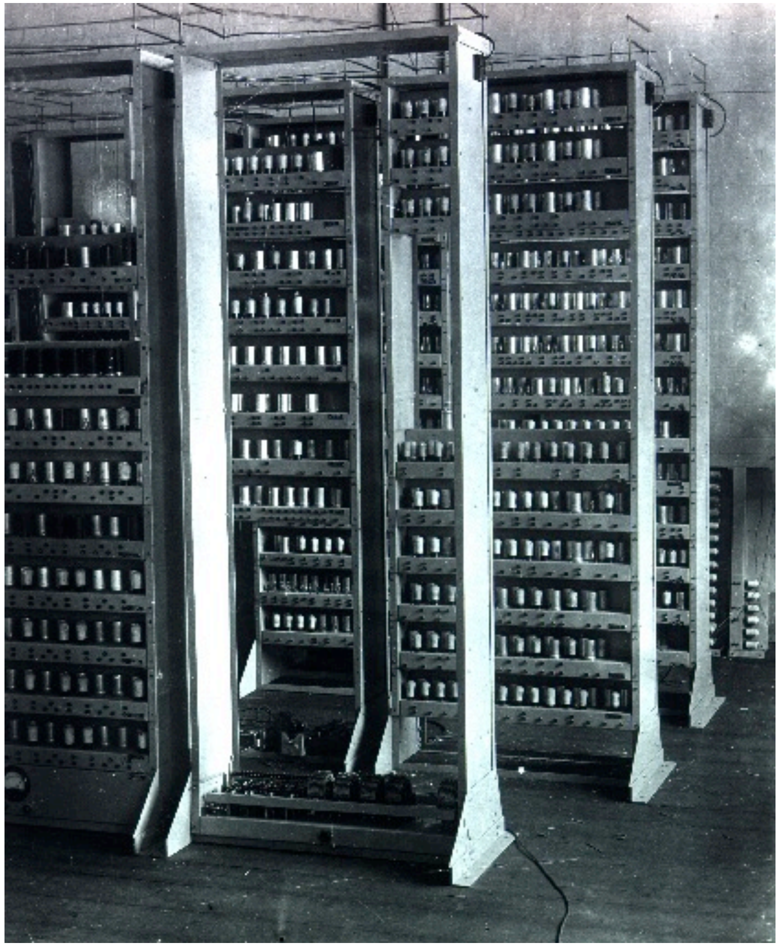
removable

portability

backup

large ROM

EDSAC / wikipedia.org



future paradigm shifts? distributed net storage?

the need for hard disks (tech)

volatility of semiconductor memories!

some sort of nonvolatile storage necessary

why not just battery backup of SRAM?

cost per GB

SRAM/DRAM are too expensive

Flash is too expensive

cache RAM is more expensive

size & throughput

higher latency, but bandwidth is huge

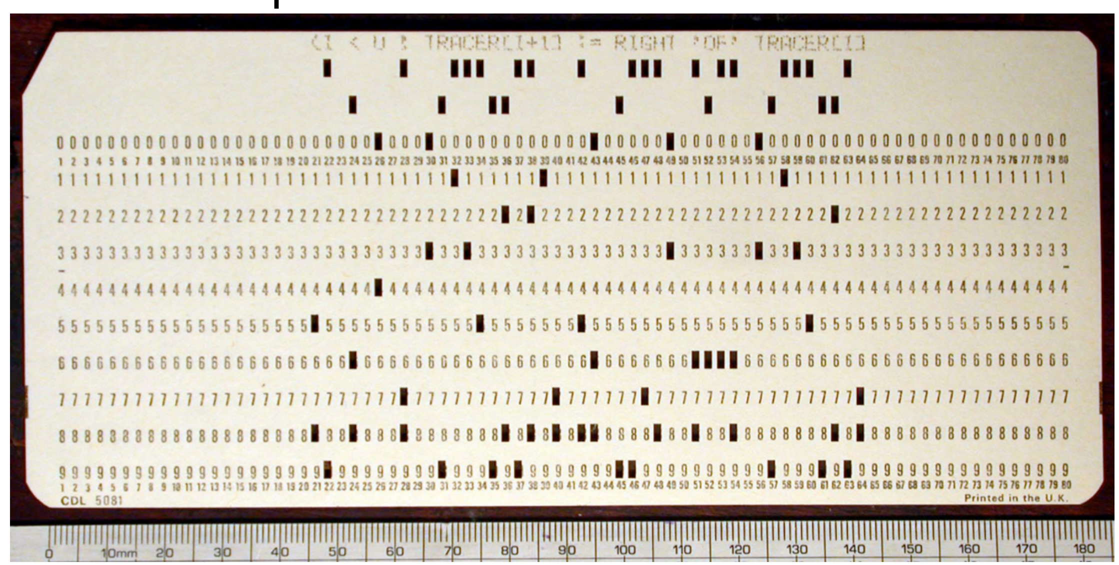
enormous sizes

endurance

essentially unlimited cycling

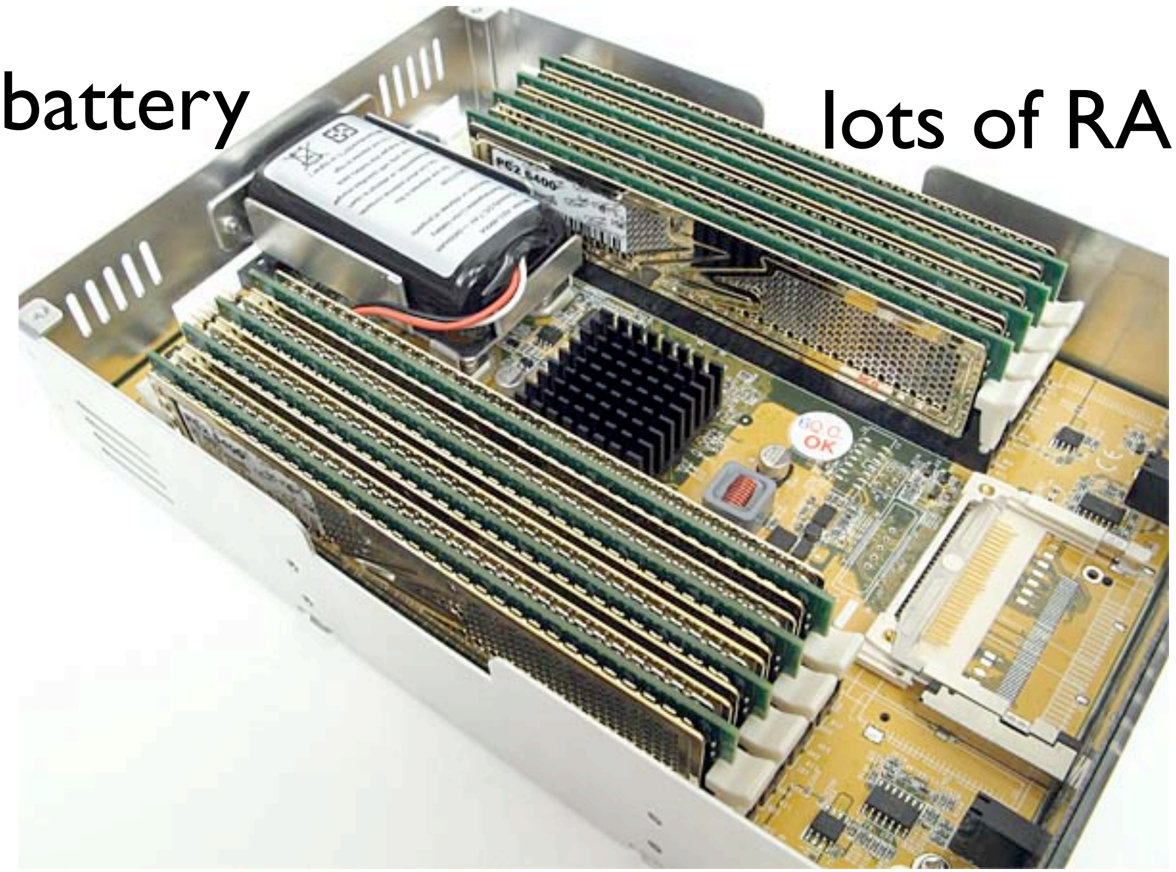
radiation hard

punched cards are nonvolatile



Back in the day, disks were expensive.

Sometimes, we would trick the system into using RAM as a disk to avoid swapping floppies.



now RAM disks make a comeback ...

the need for mass storage (human)

sound

several MB per minute / lossy
tens of MB per minute / “lossless”

pictures

several MB per image

video

~ 1 MB per sec
several GB per movie
with lossy compression!

data mining

enormous sizes

apple.com

how do hard disks work, more or less?

wikipedia.org - "Hard_Disk"

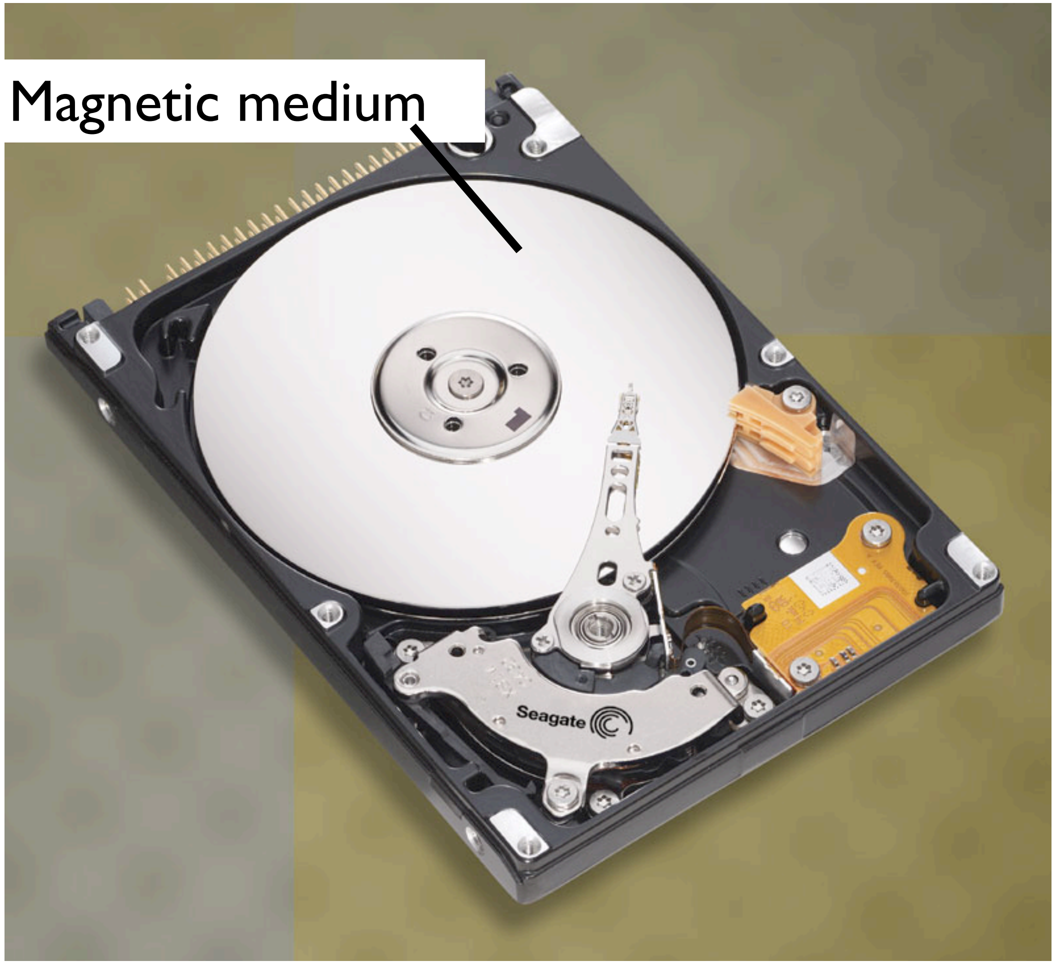
spinning (~10^4 rpm) part holds data.
sliding part reads and writes data.

hard disk drives

160 Gbit 2.5” perpendicular drive for laptops

images from M. Coey

hard disk drives



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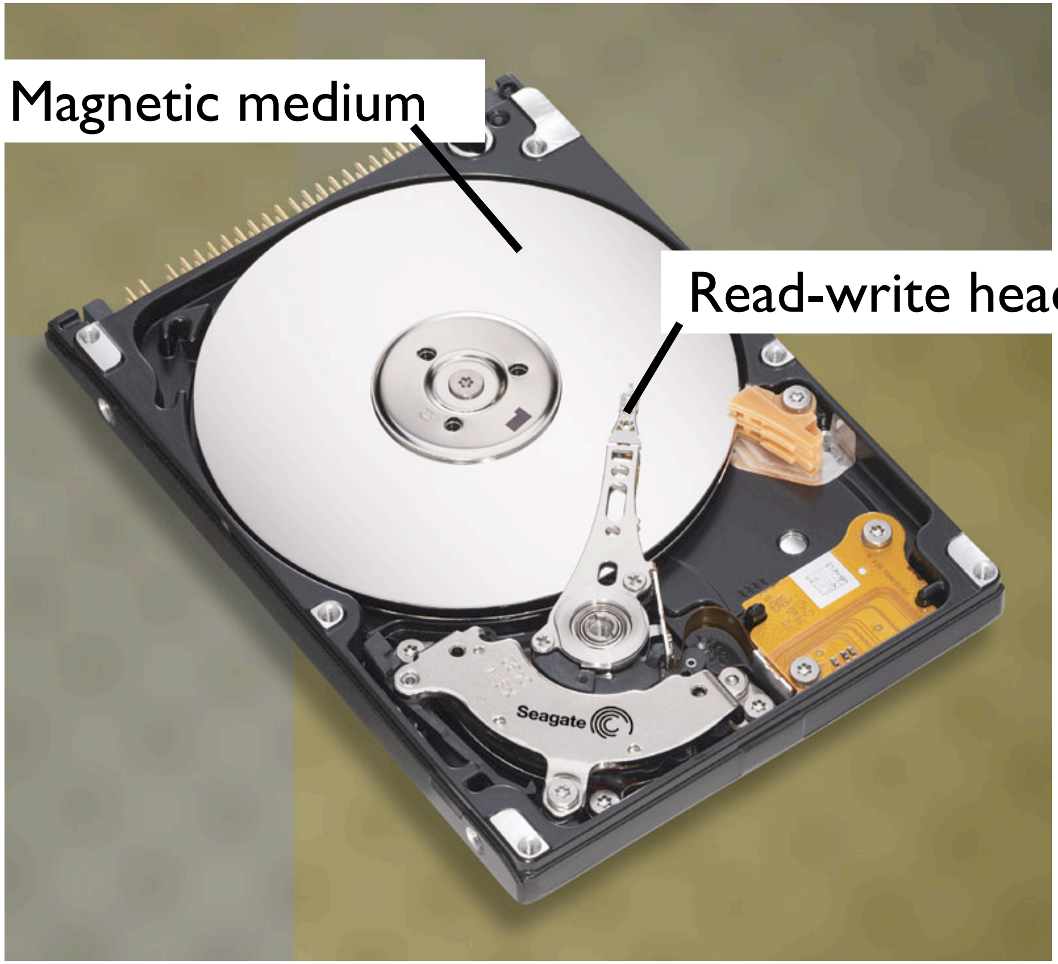

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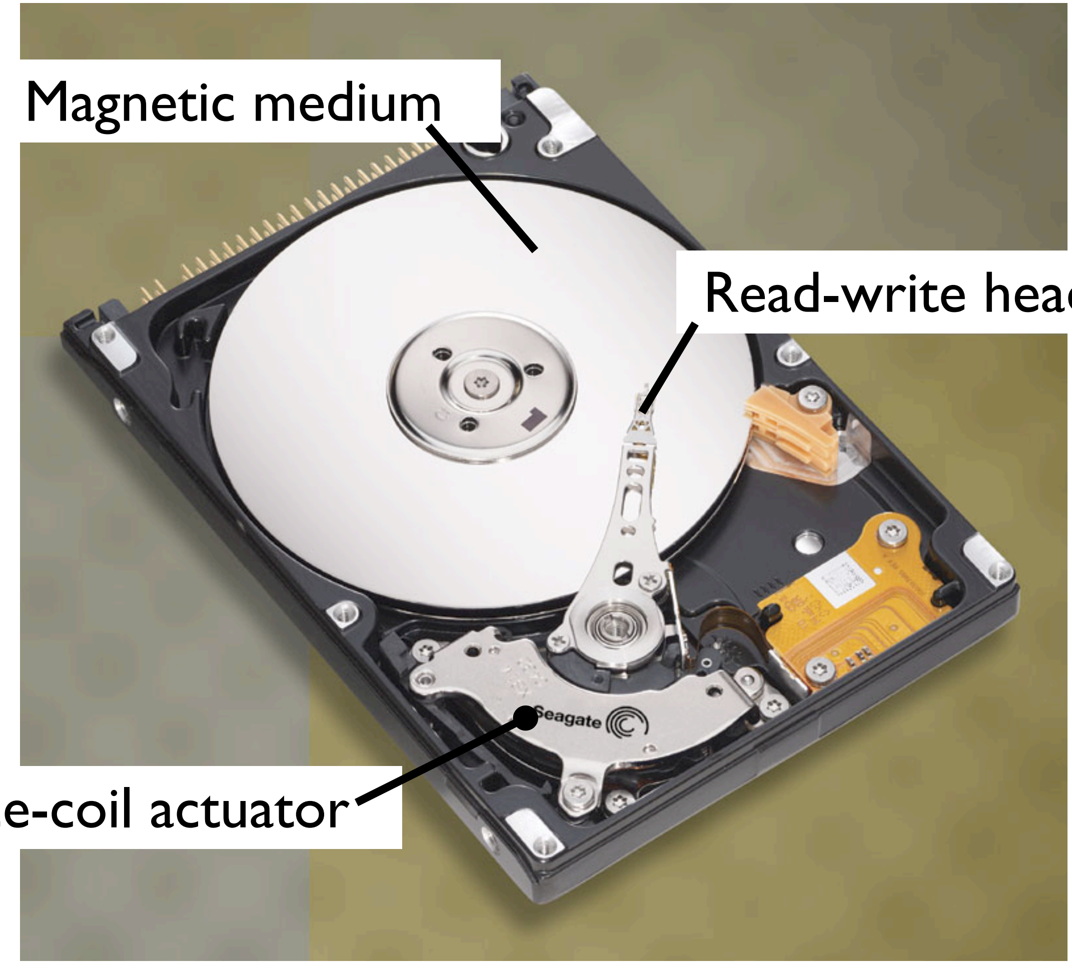

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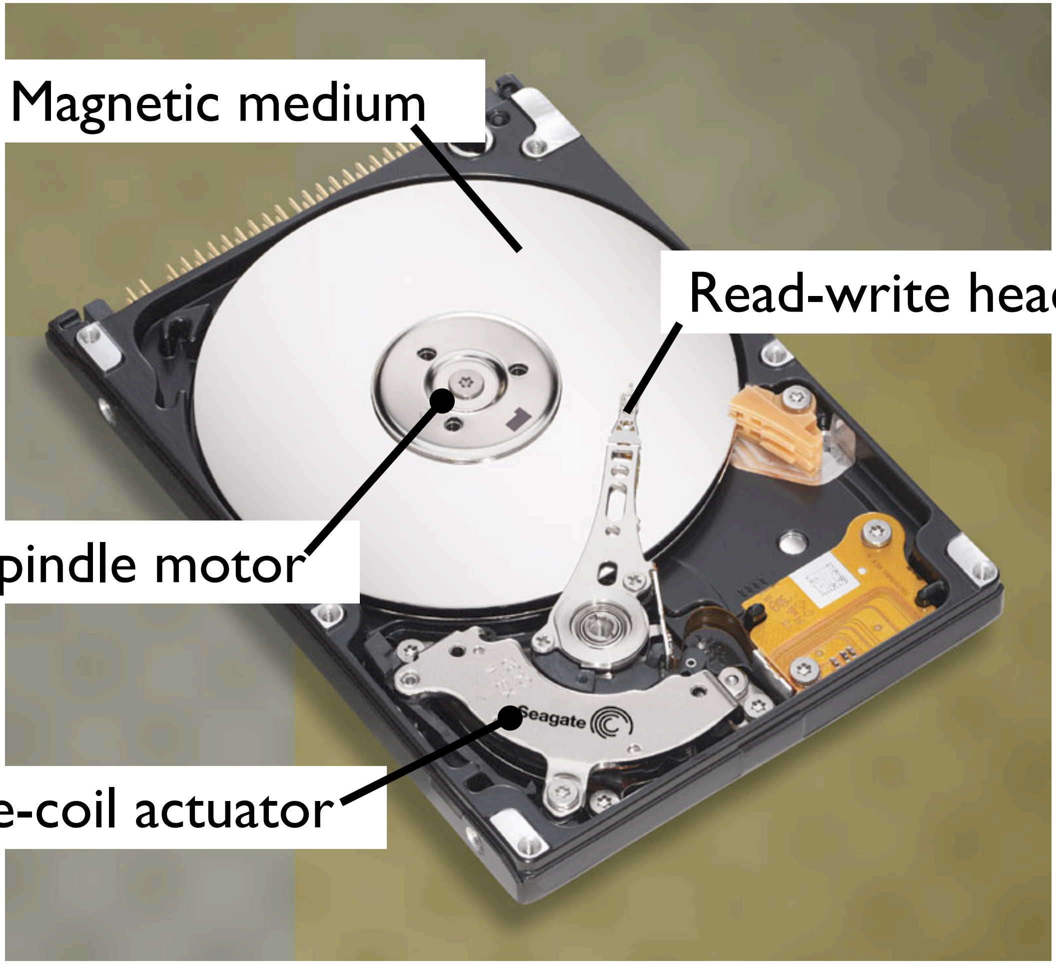

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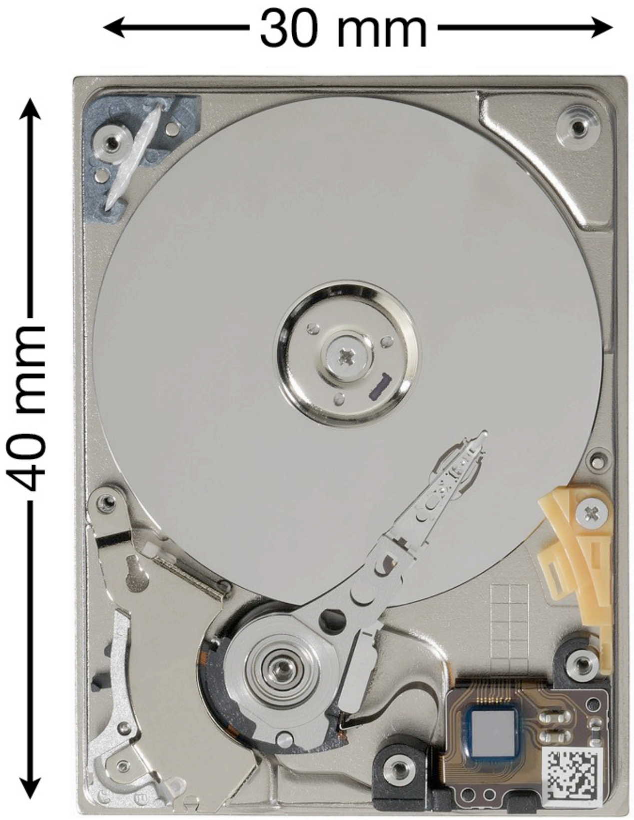
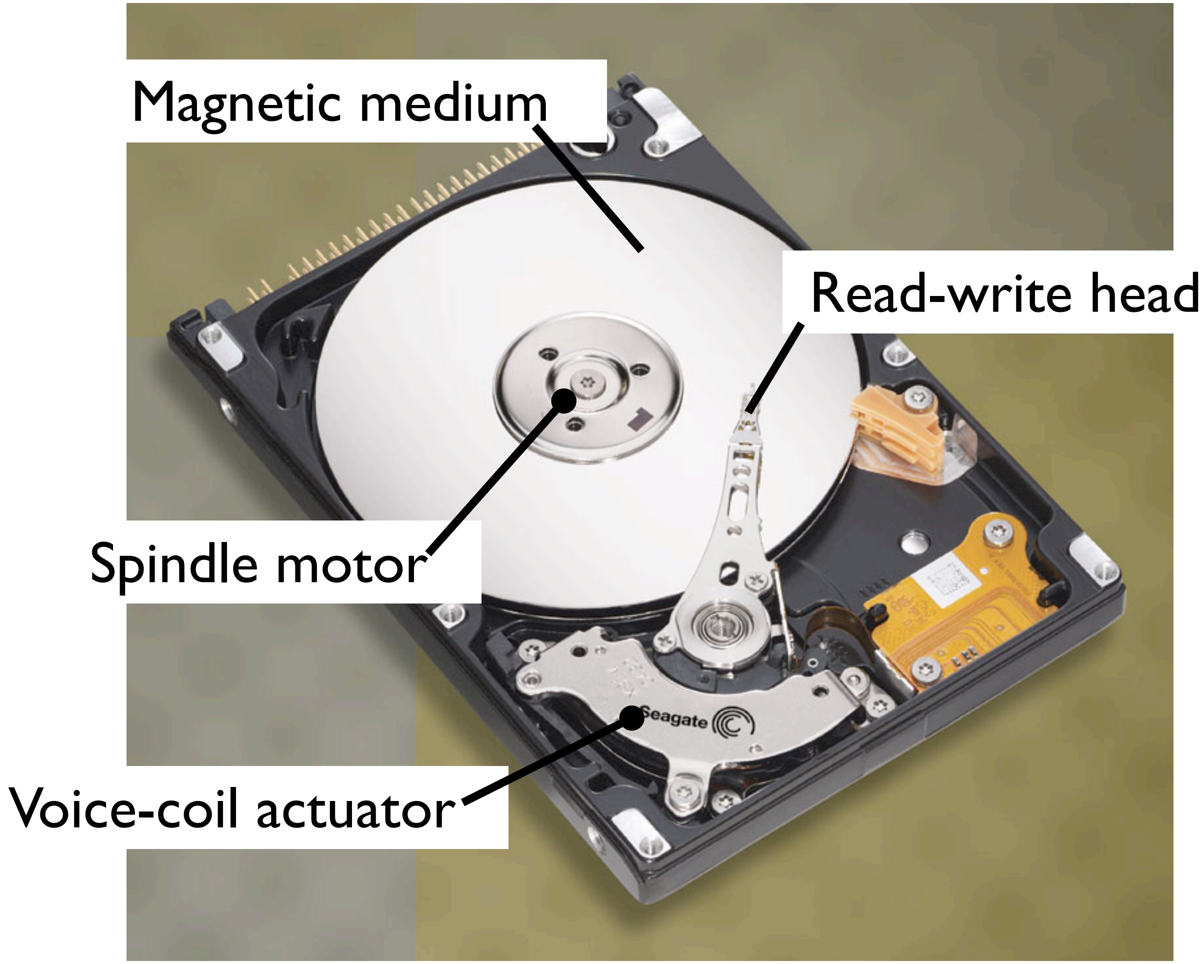


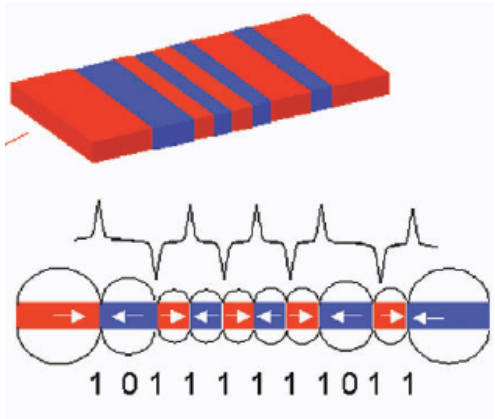
8 Gbit 1” drive for cameras



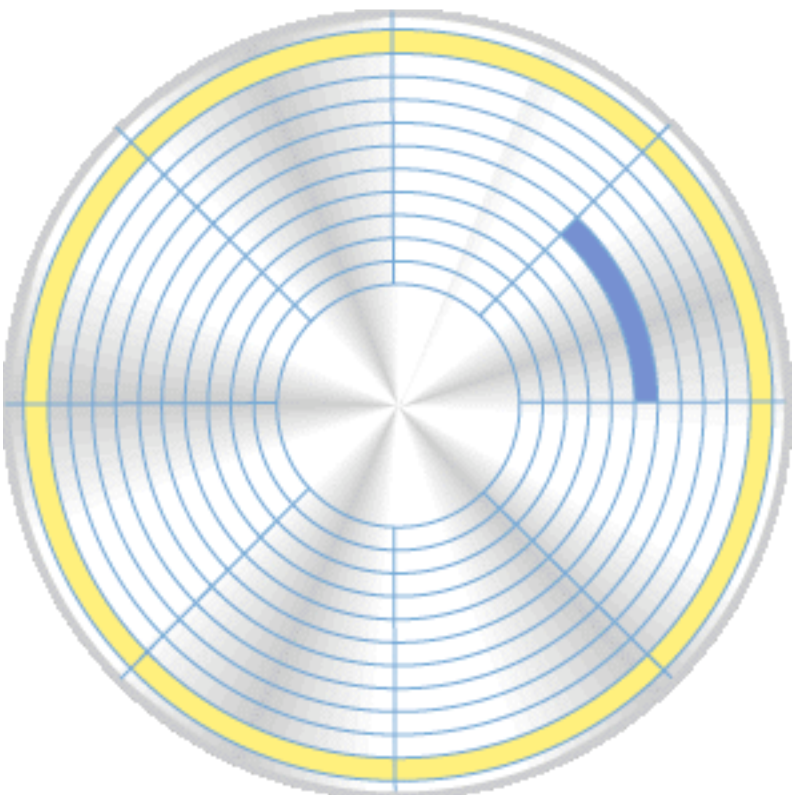
160 Gbit 2.5” perpendicular drive for laptops

images from M. Coey

media basics



Hard disk
- tiny magnetized regions
- direction (N/S) stores bit
- magnetic sensor reads bits

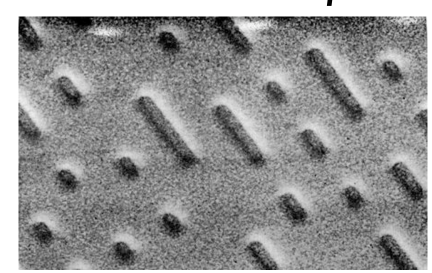


LP records
- tiny bumps
- needle moves

actual record grooves

CDs
- pits store bits
- optical reflectivity

actual CD surface



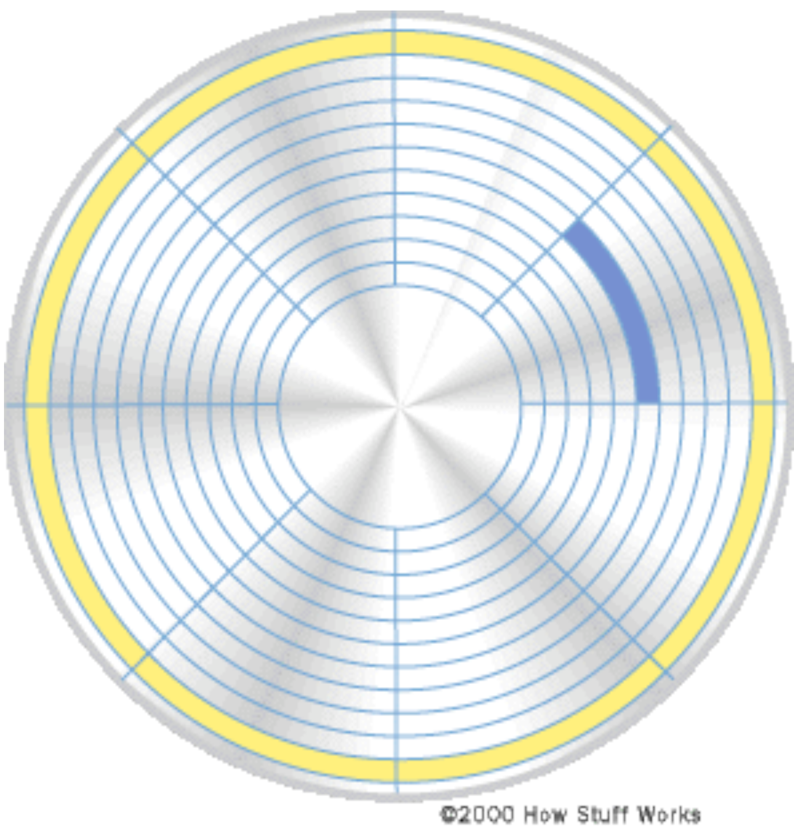
media basics

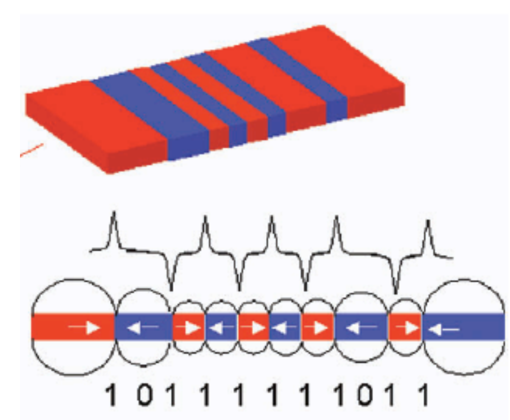
hard disk platters are round.

so how is data arranged?

tracks = concentric circles
sectors = wedge of a track

sector has fixed # bytes

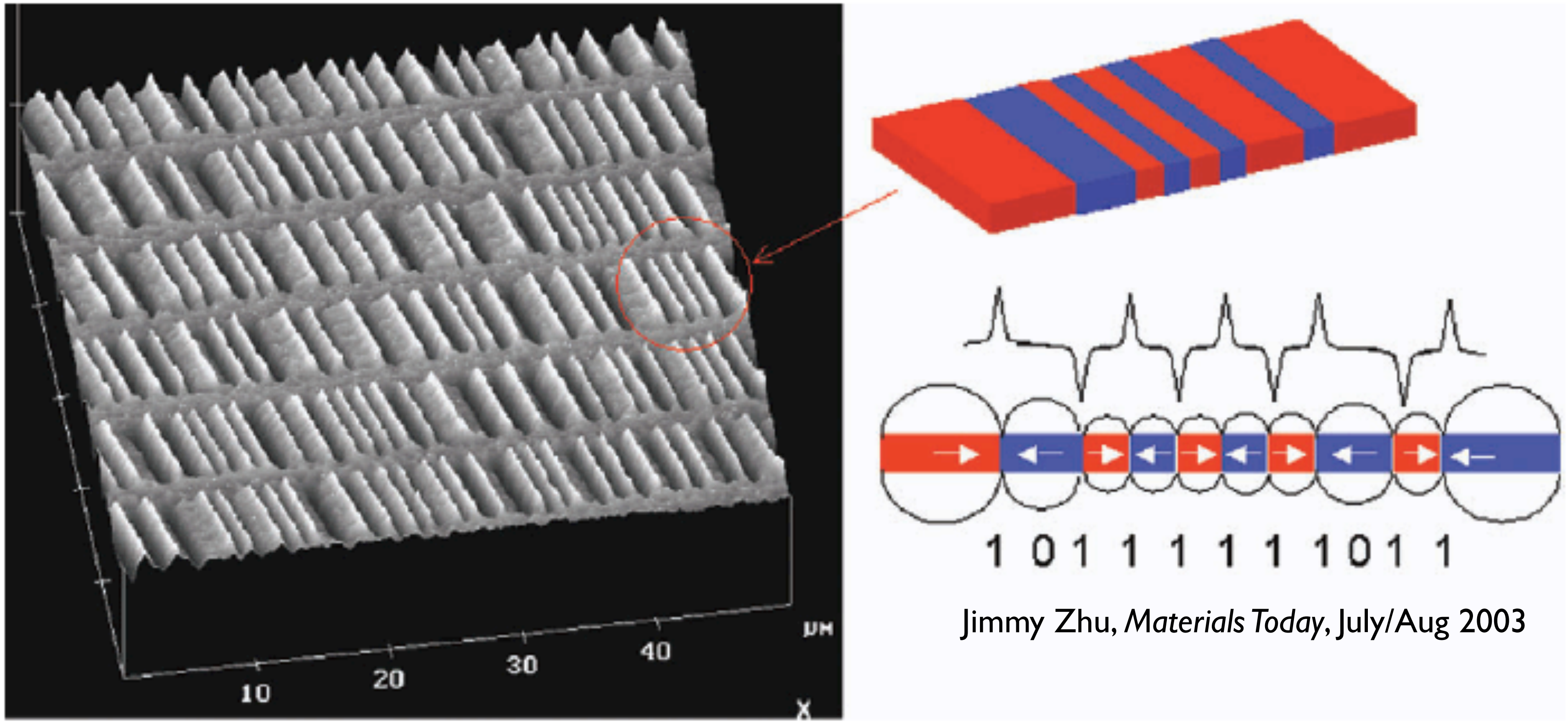




media basics

mfm image

sees transition field



Jimmy Zhu, *Materials Today*, July/Aug 2003

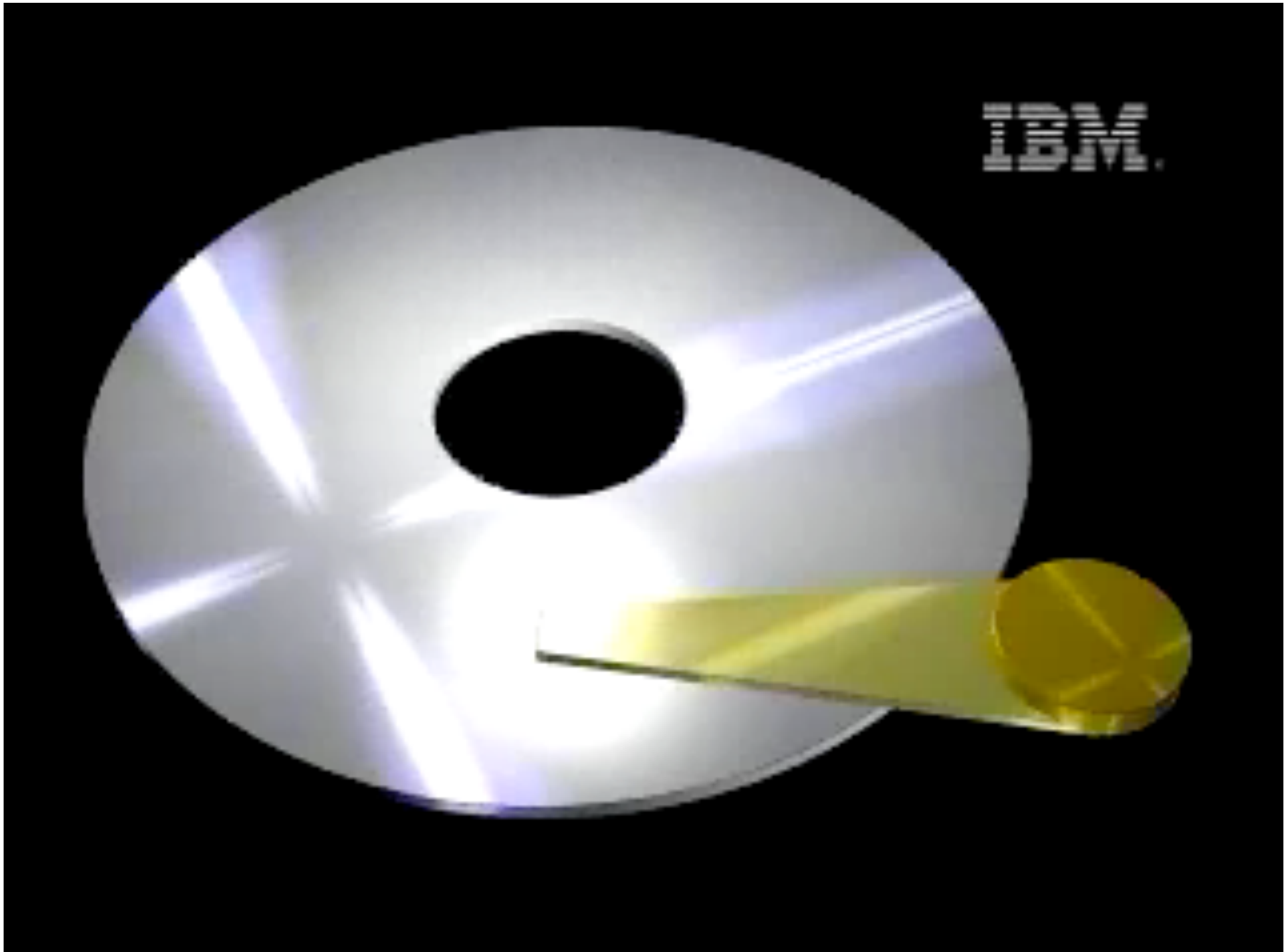
CoCrPt alloy

platters - Al or glass substrate

typical magnetic region

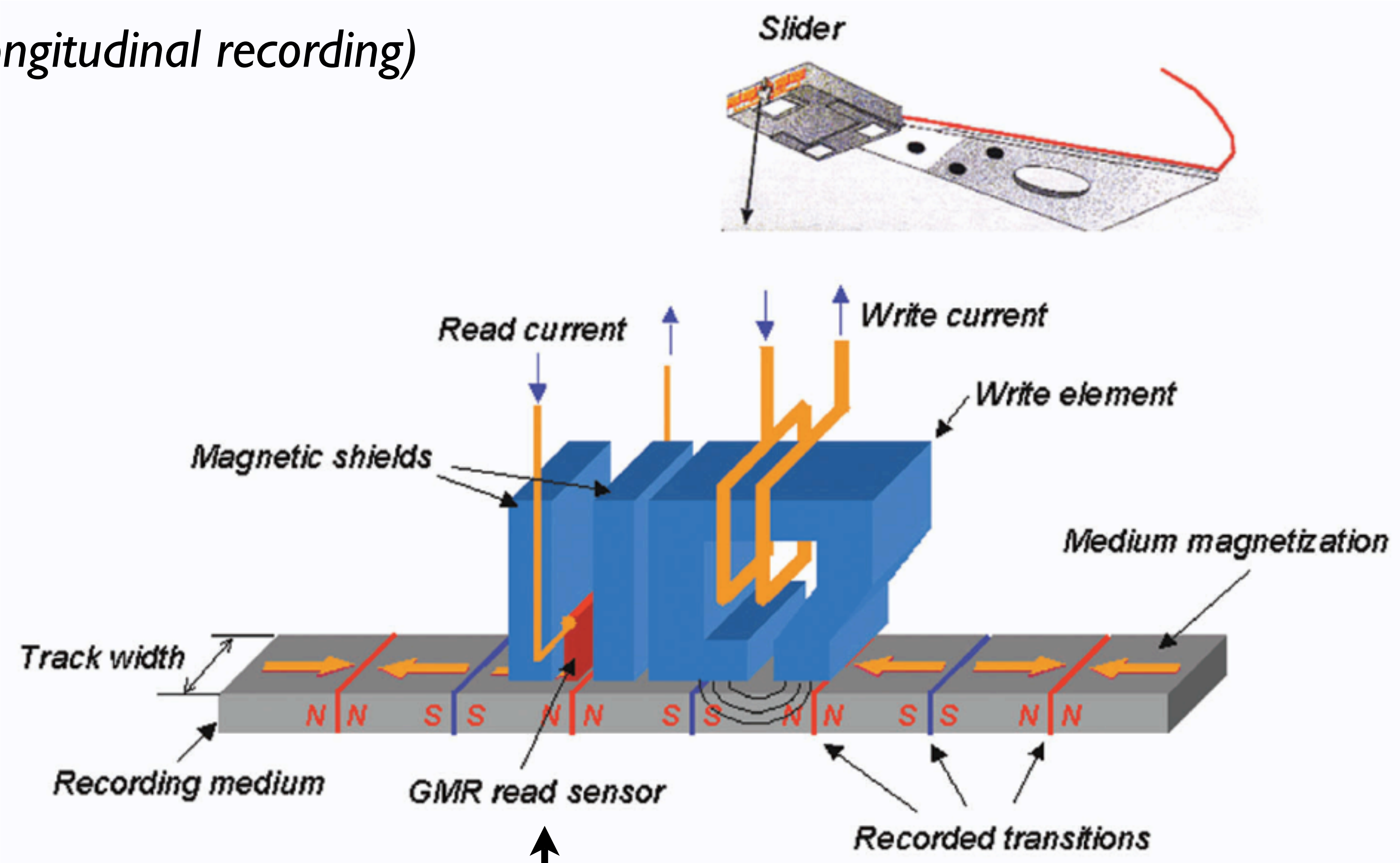
~200-250 nm wide, ~25-30 nm down-track

100 billion bits (Gigabits) per in^2


IBM

reading and writing basics

(longitudinal recording)



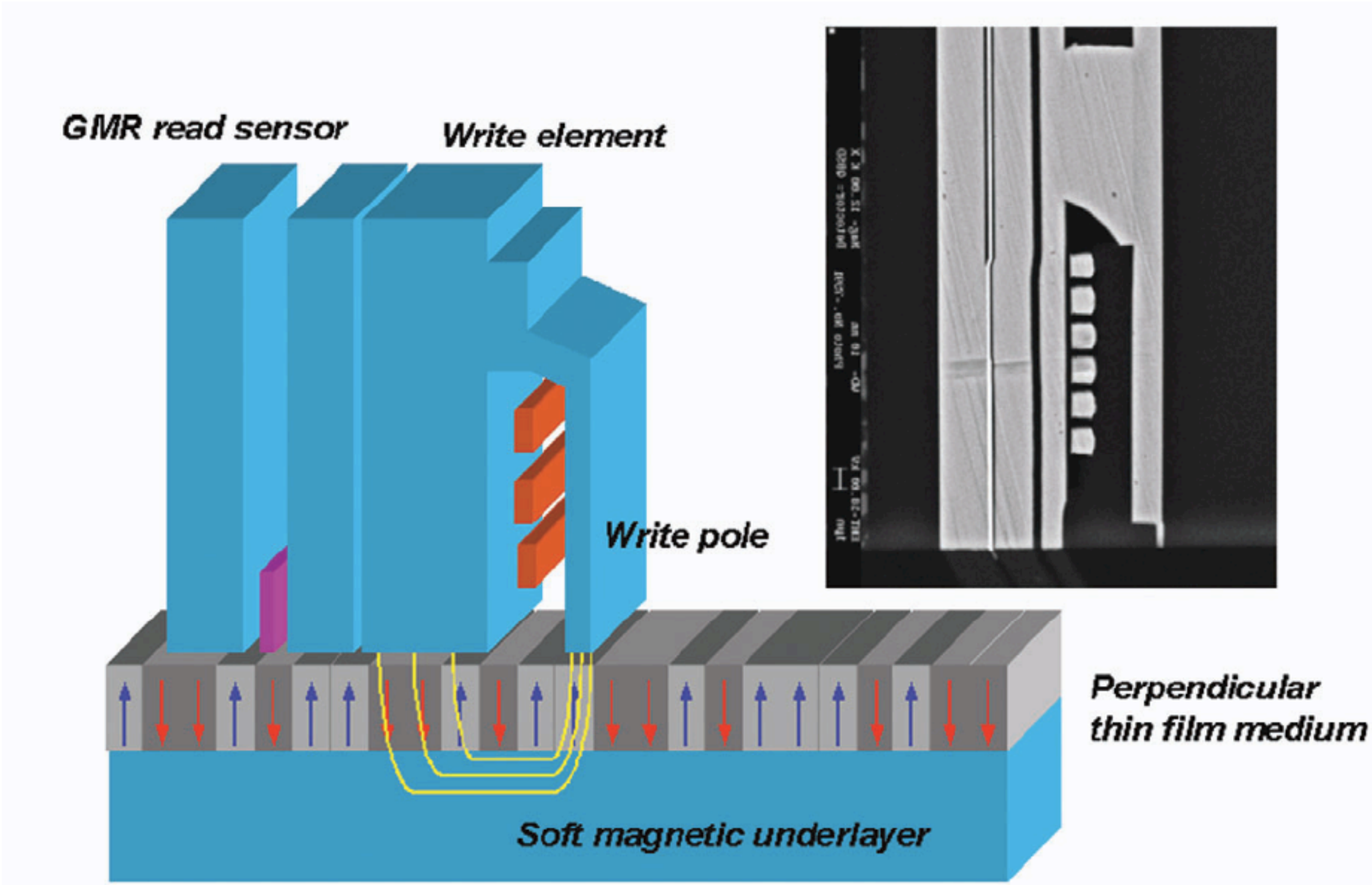
sensor - *magnetoresistive*

Jimmy Zhu, *Materials Today*, July/Aug 2003

reading and writing basics

(perpendicular recording)

Jimmy Zhu, *Materials Today*, July/Aug 2003

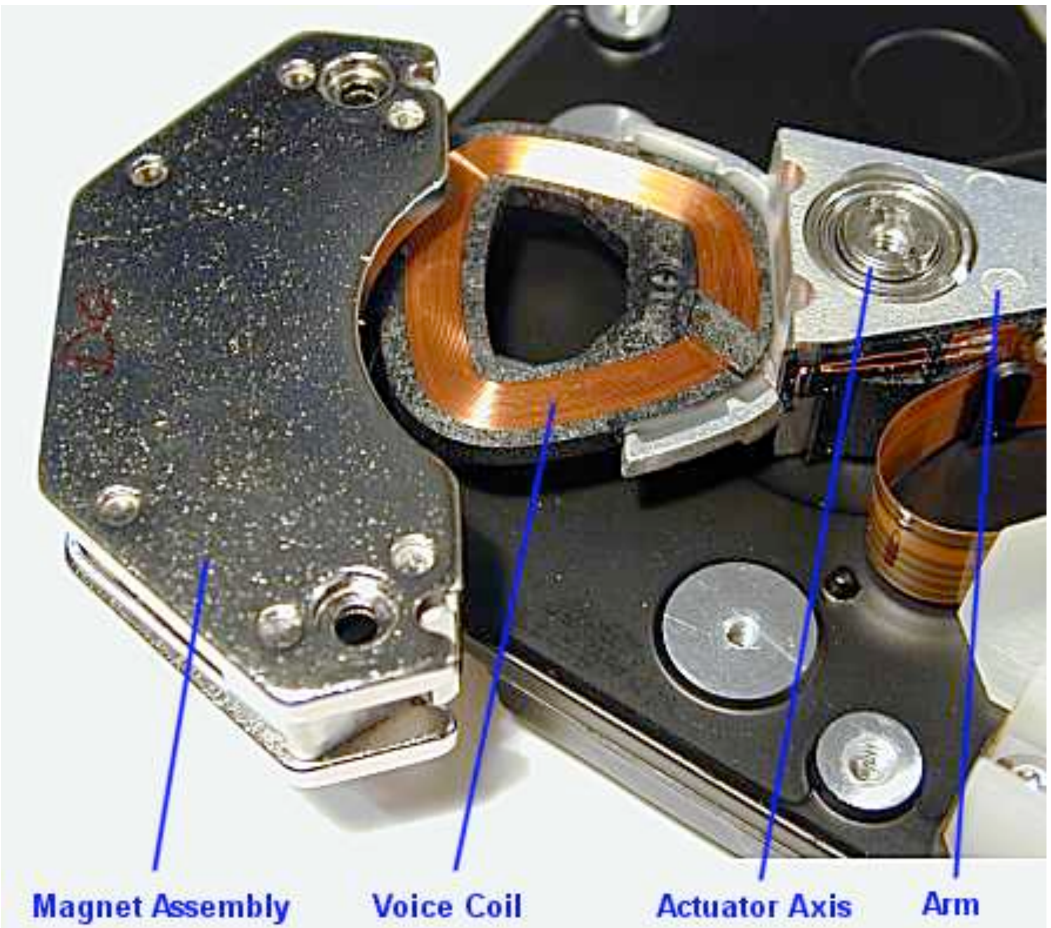


soft underlayer becomes part of the flux guide
... careful concentration of flux ...

read head (and its reflection)

positioning basics

- current powers voice coil†
- field generated moves head L or R
- more precise than stepper motor



www.pcguide.com/ref/hdd/op/actActuator-c.html

† this is the same way a speaker cone moves

positioning basics

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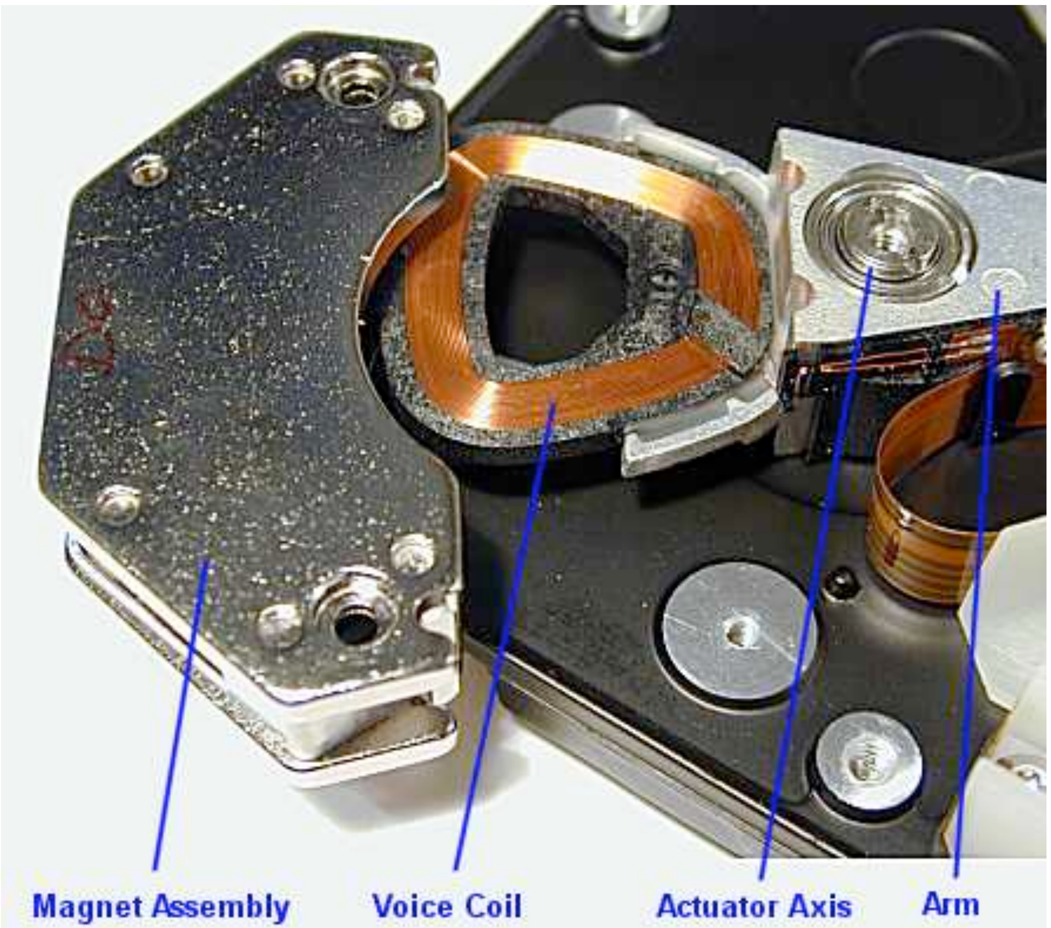
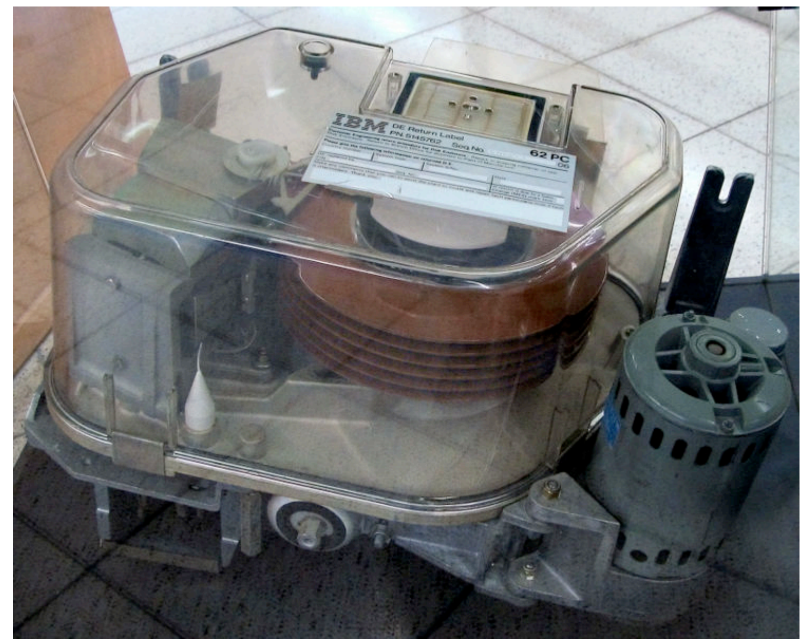


www.pcguide.com/ref/hdd/op/actActuator-c.html

IBM 62PC "Piccolo" HDD, ~1979 - an early 8" disk



wikipedia.org - “Hard_Disk”

† this is the same way a speaker cone moves

why magnets?

microscopic view

magnets remember their state

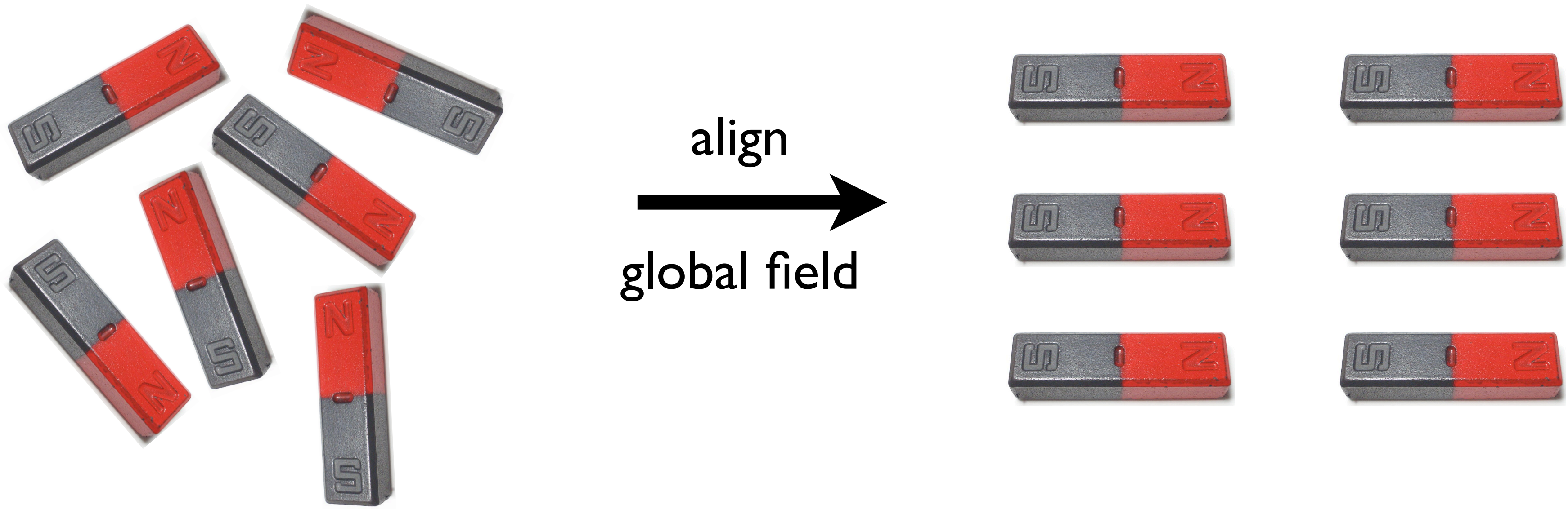
once magnetized, they stay that way

with a little bit of energy, we can control them

switch from N to S

why magnets?

microscopic view



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microscopic view

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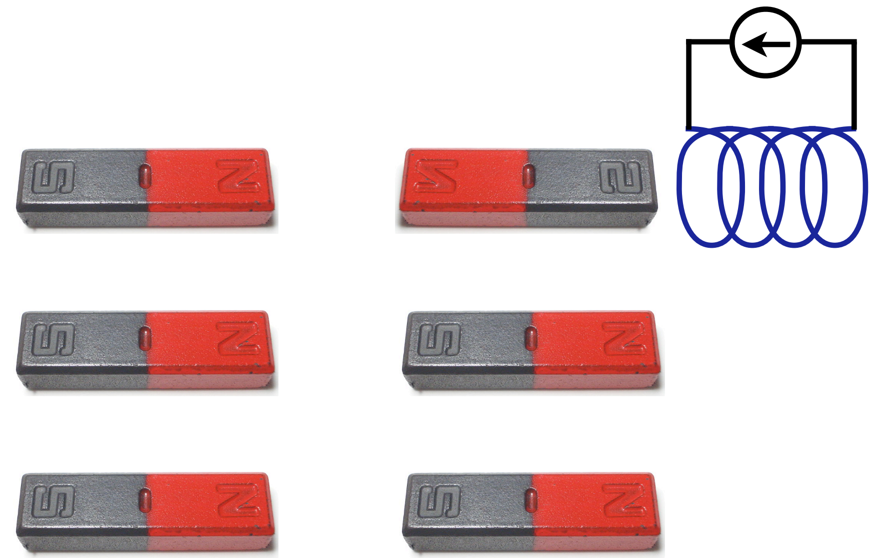
why magnets?

microscopic view

address

local field



magnets remember their state

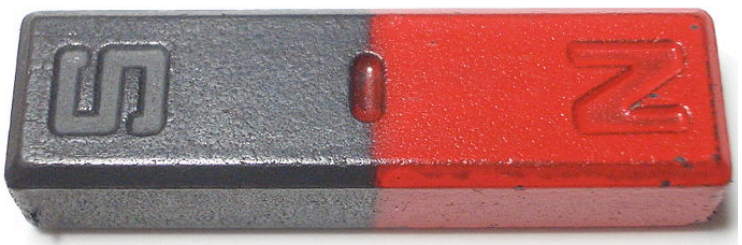
once magnetized, they stay that way

with a little bit of energy, we can control them

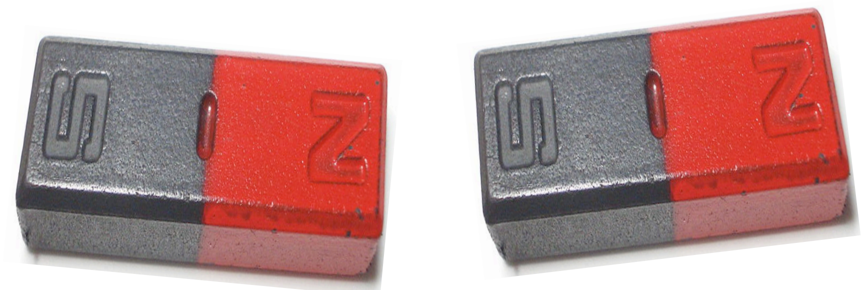
switch from N to S

why magnets?

what happens when you break a magnet?



you get two magnets



now: do this 25 more times

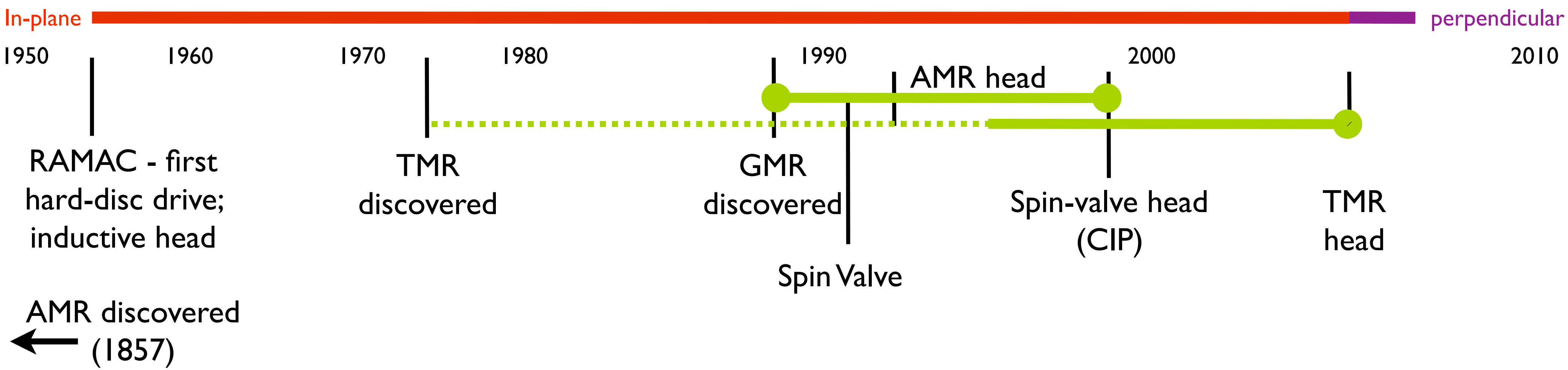
➠ 33 million magnets, all 50nm across

about 1,000 times thinner than a hair

we can make *really tiny* magnets

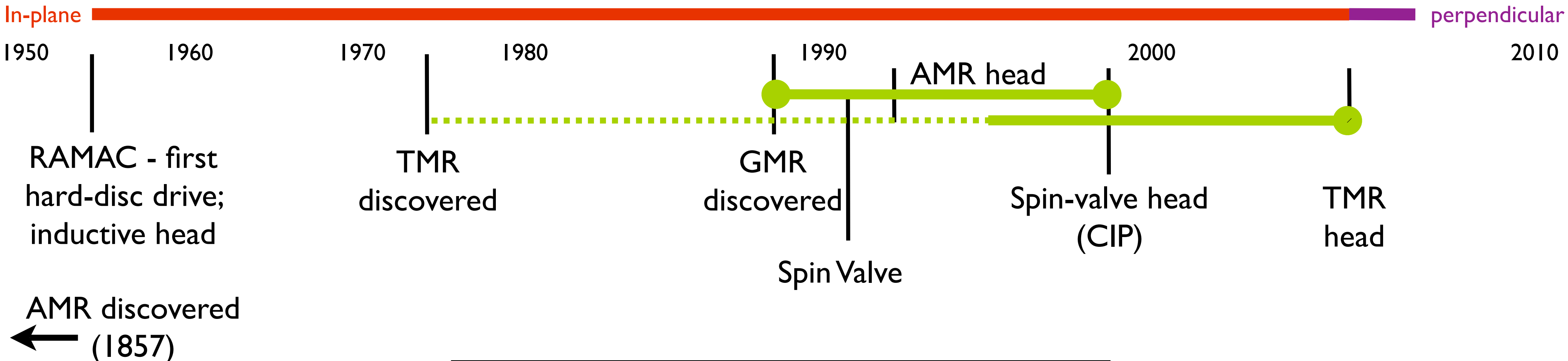
smaller is *better*, to a point

technology timeline



images and text from M. Coey

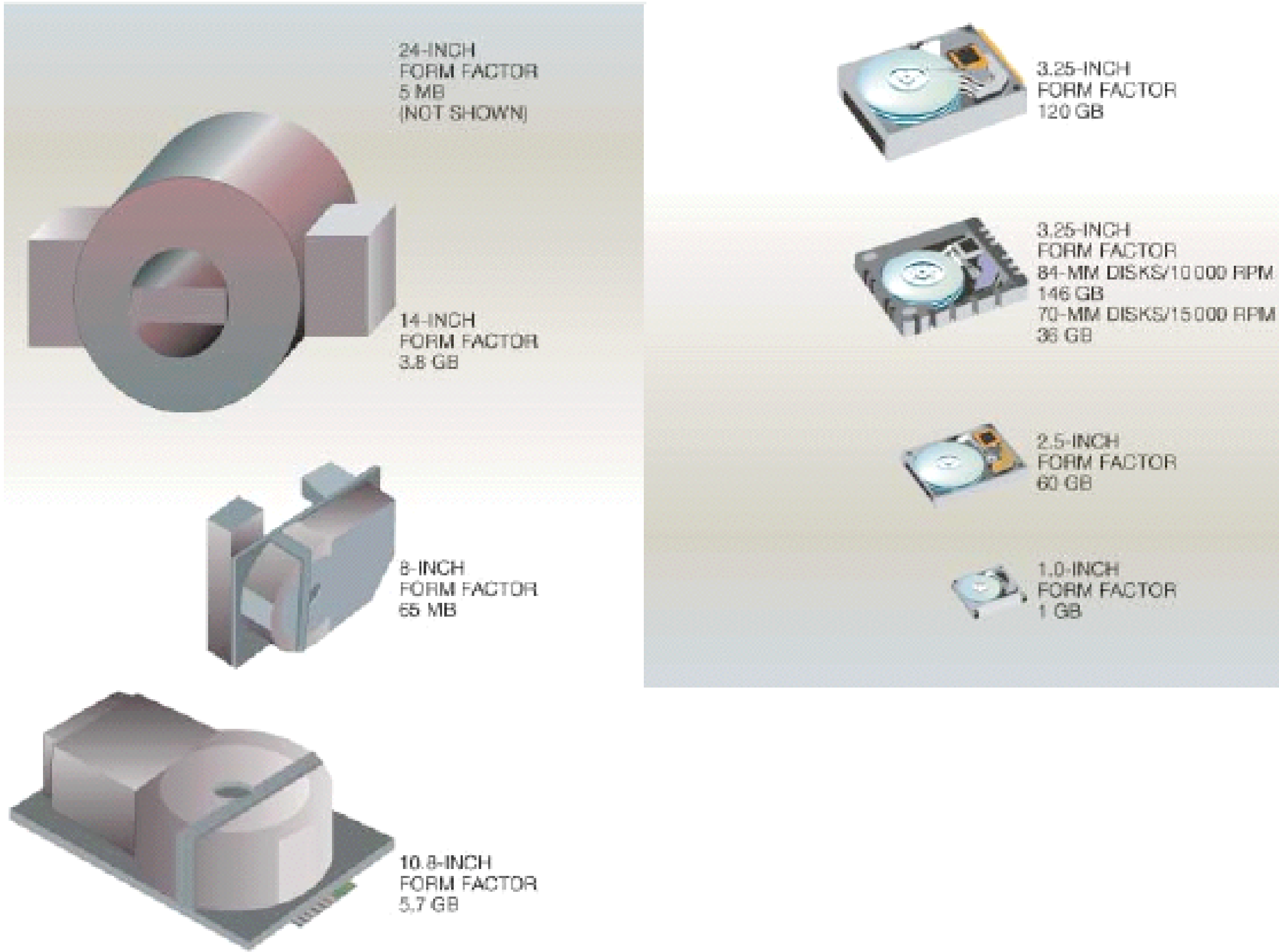
technology timeline



year	capacity	platters	size	rpm
1955	40 Mb	50x2	24”	1200
2005	160 Gb	1	2.5”	18000

images and text from M. Coey

the incredible shrinking hard disk



E. Grochowski and R.D. Halem
IBM Systems Journal, **42** (2), 2003

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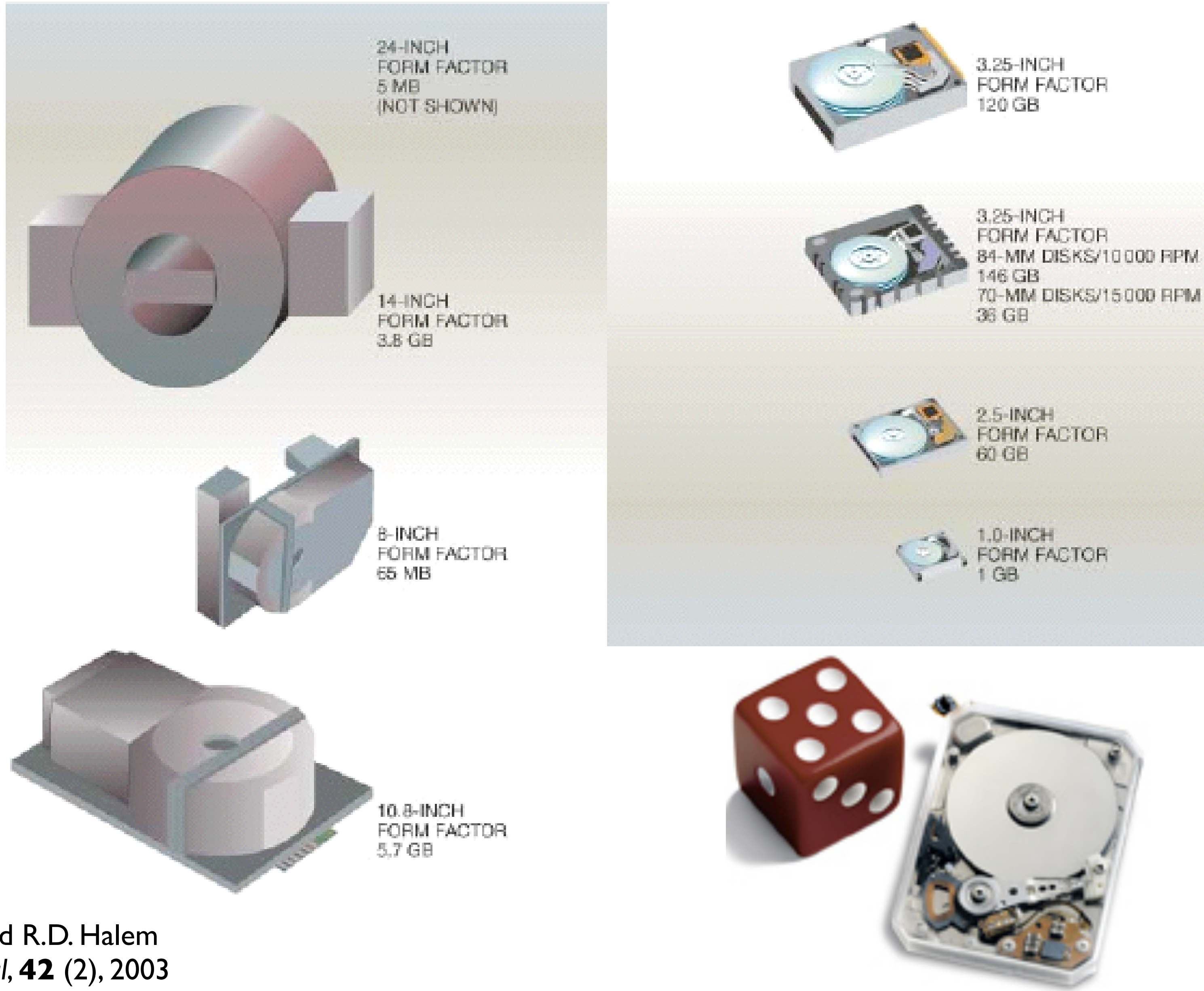

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growth of areal density

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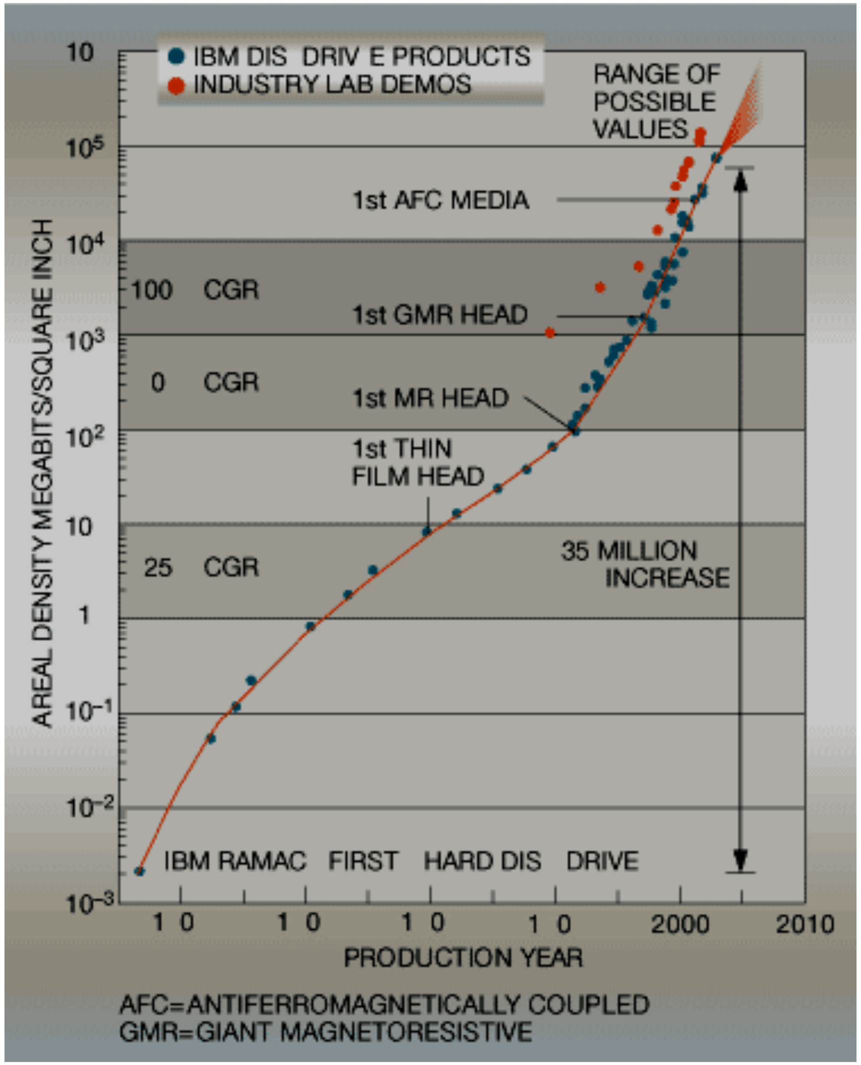

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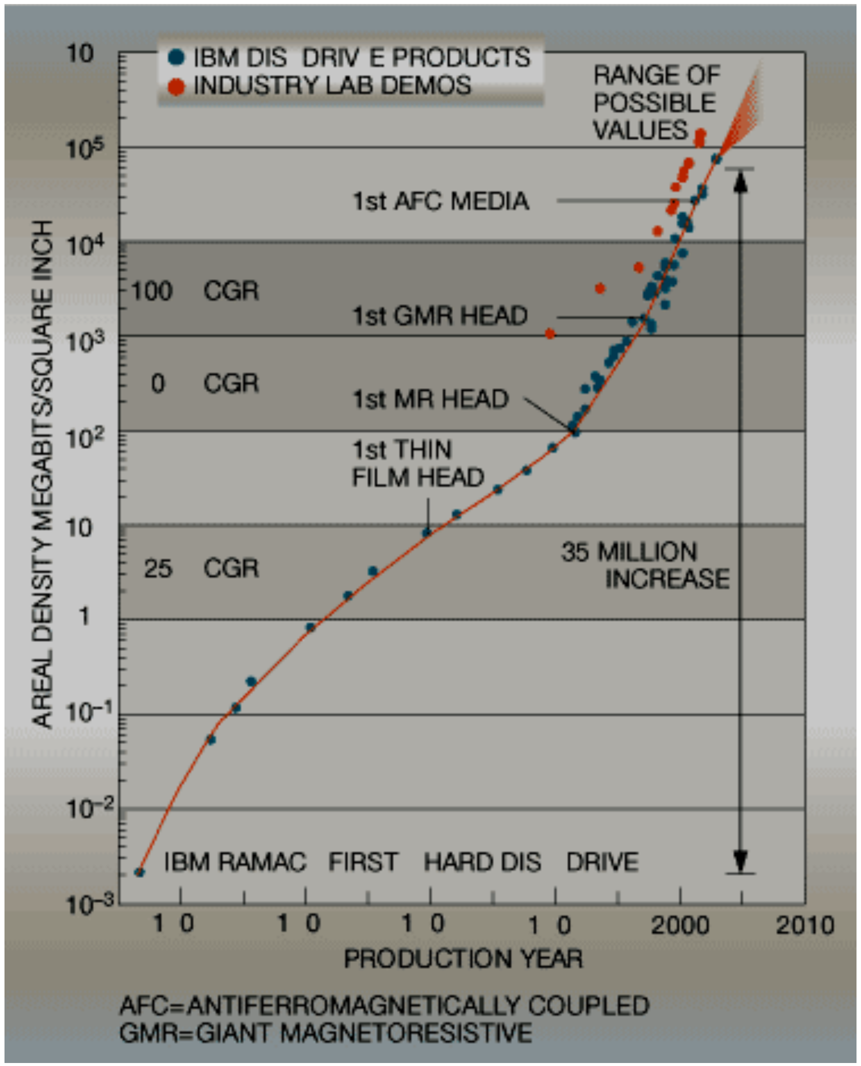

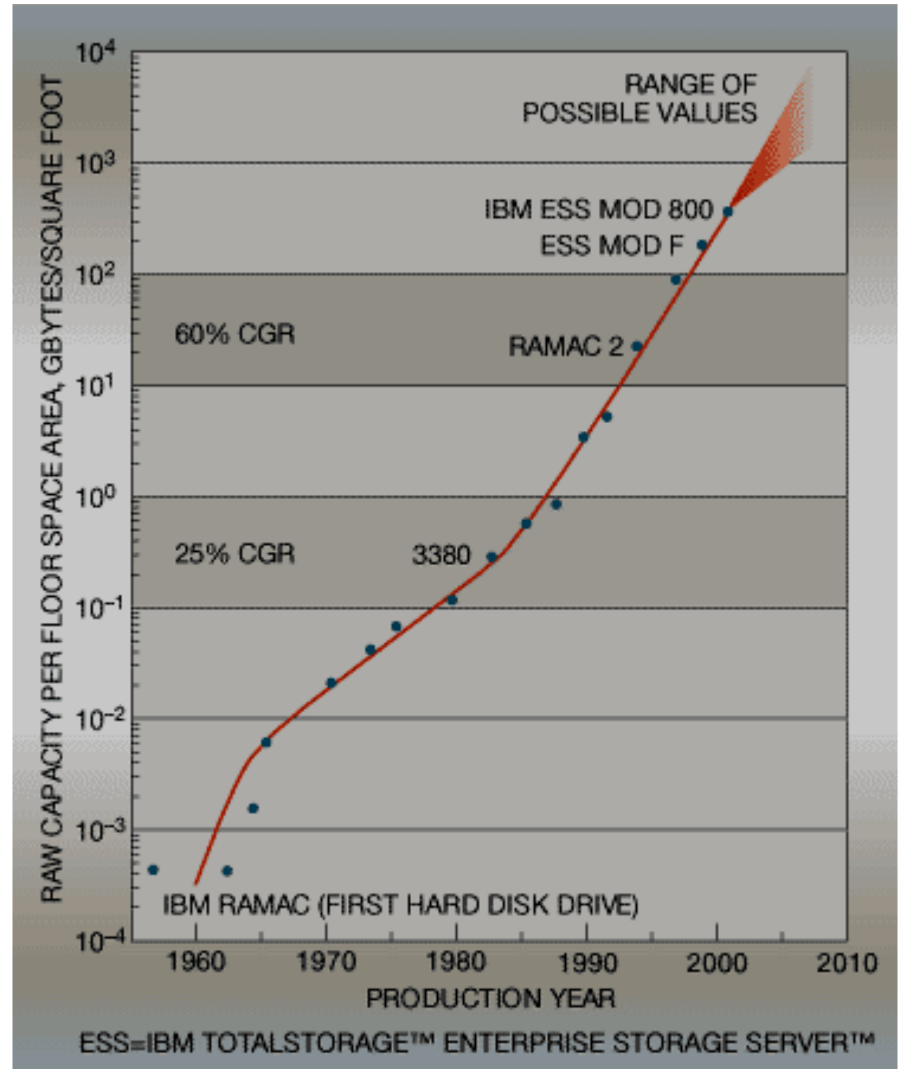

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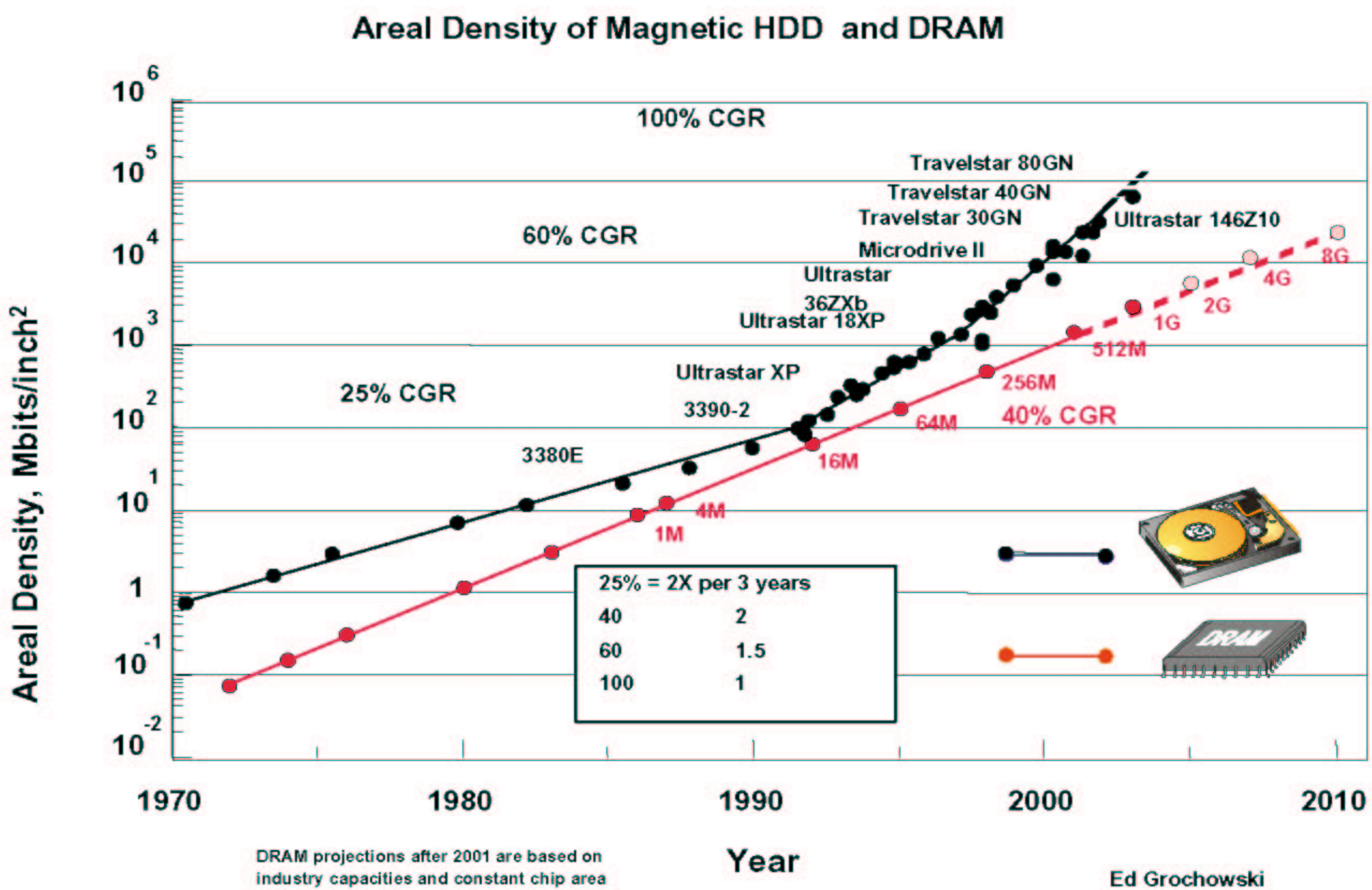
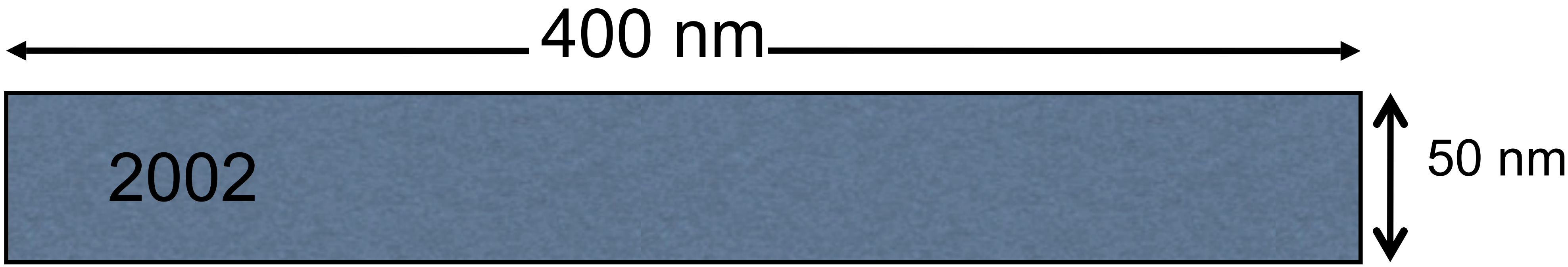
areal density *vs.* DRAM



The incredible shrinking bit!
Predicted relative sizes of HDD storage bits



(assumes areal densities continue to double yearly)

The incredible shrinking bit!
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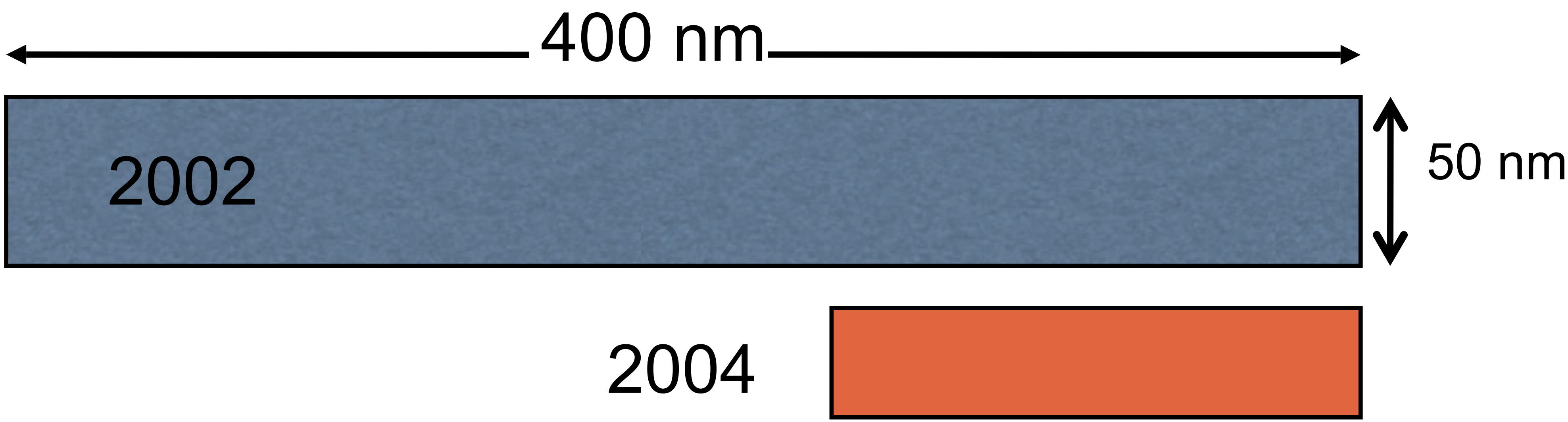

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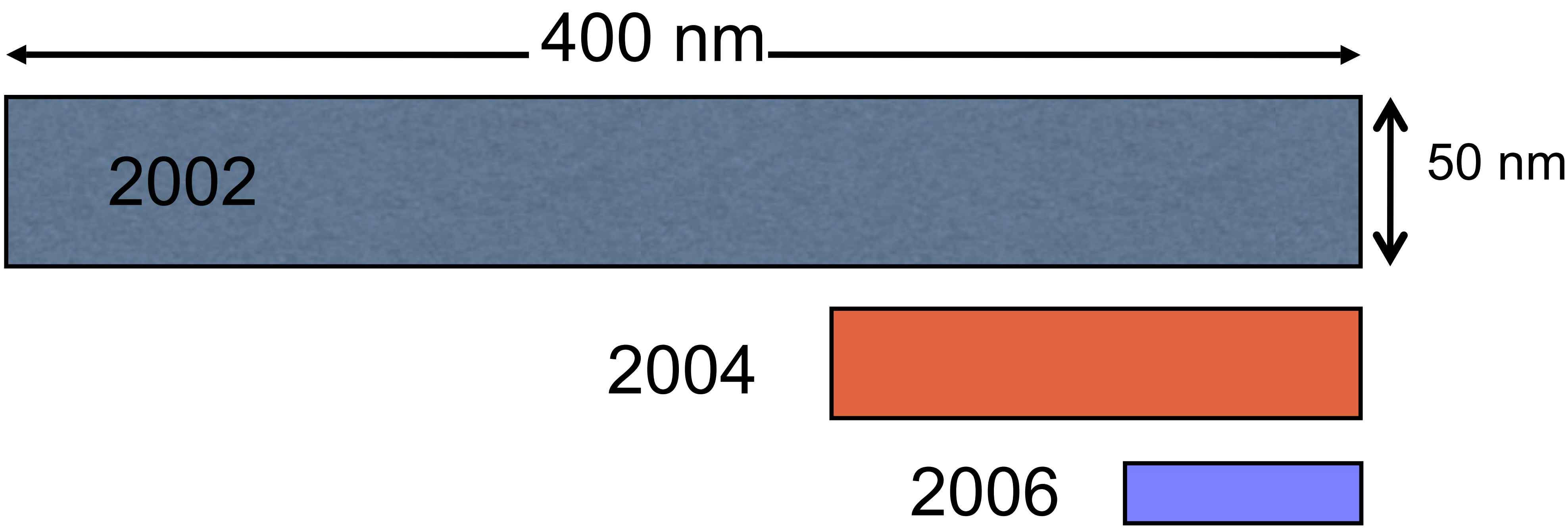

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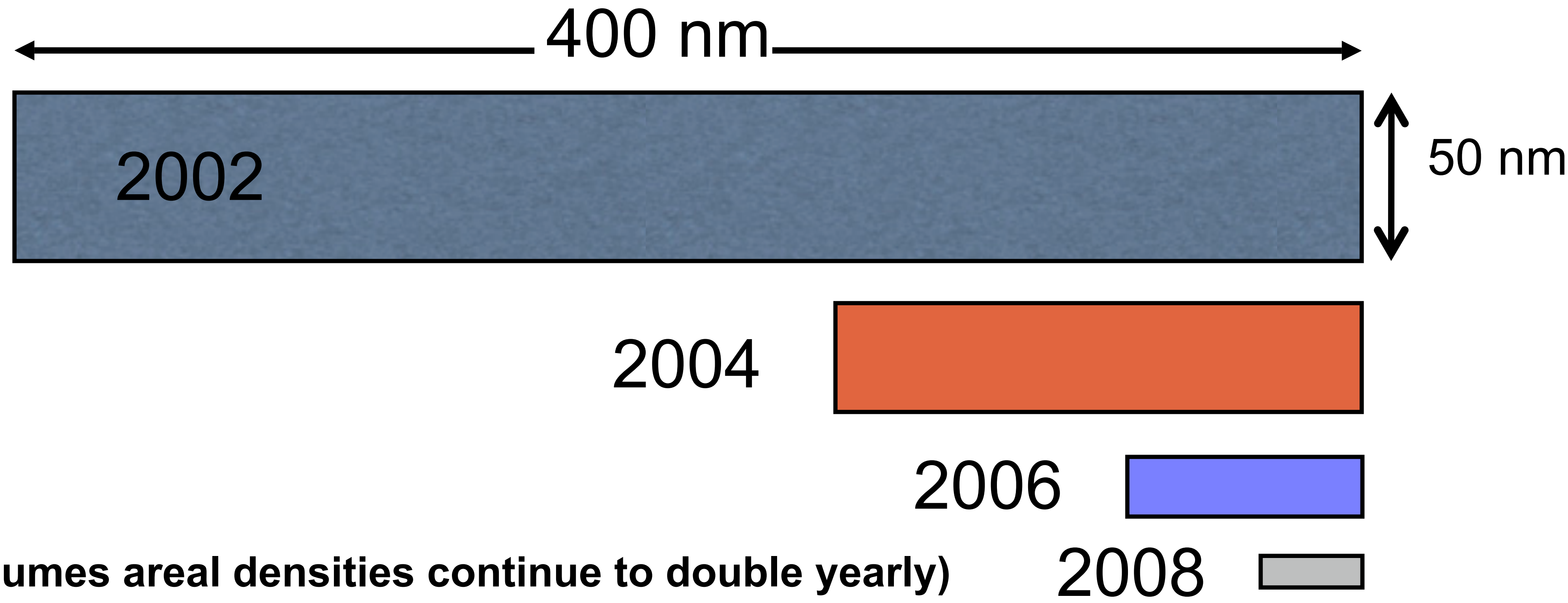

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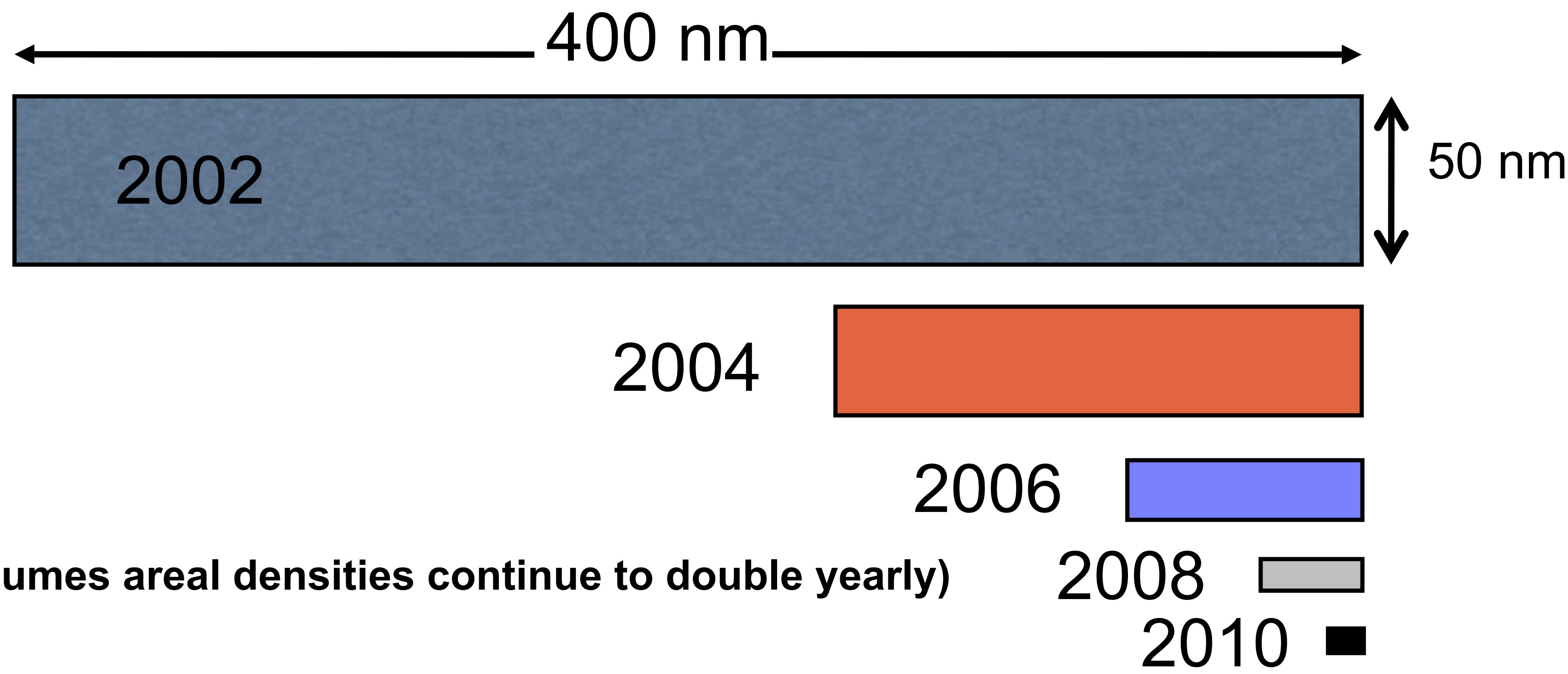

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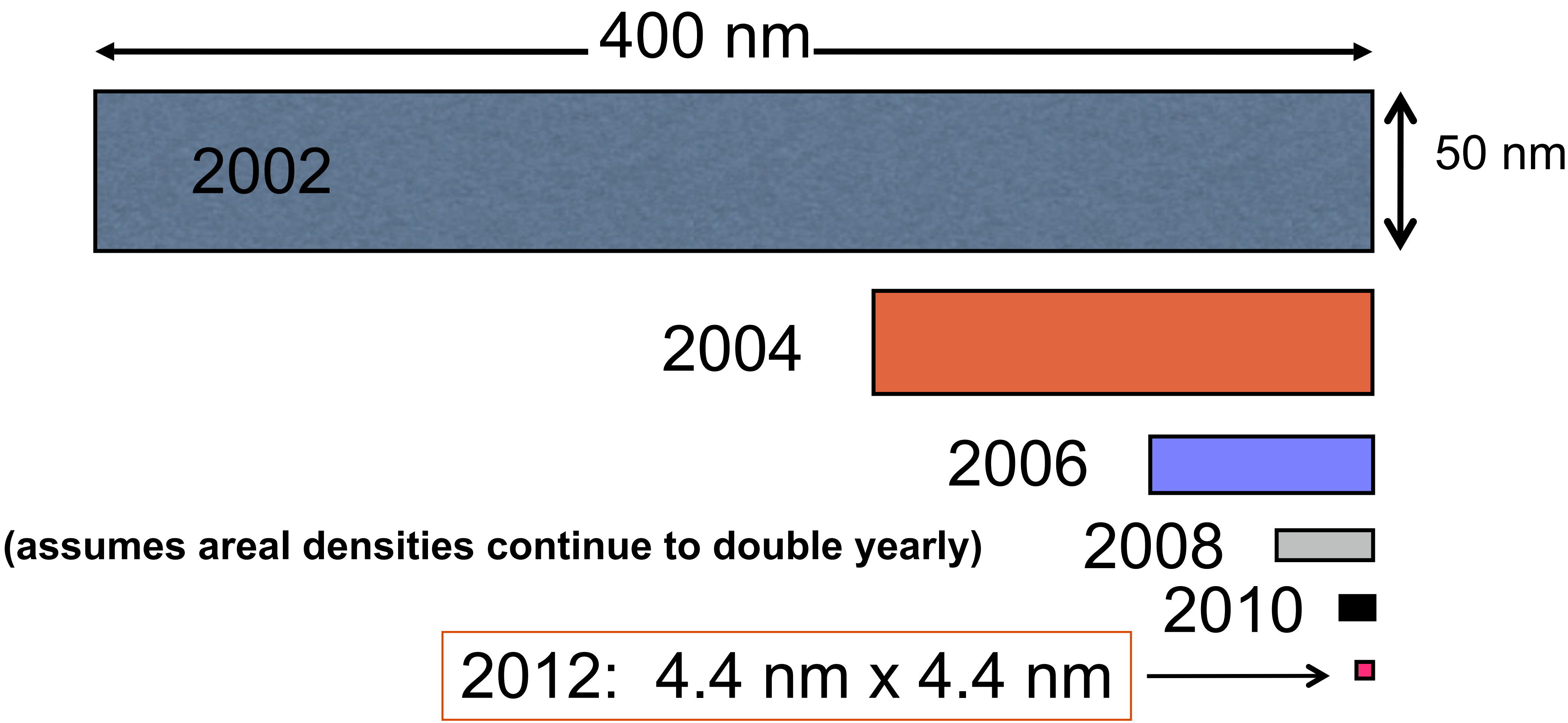

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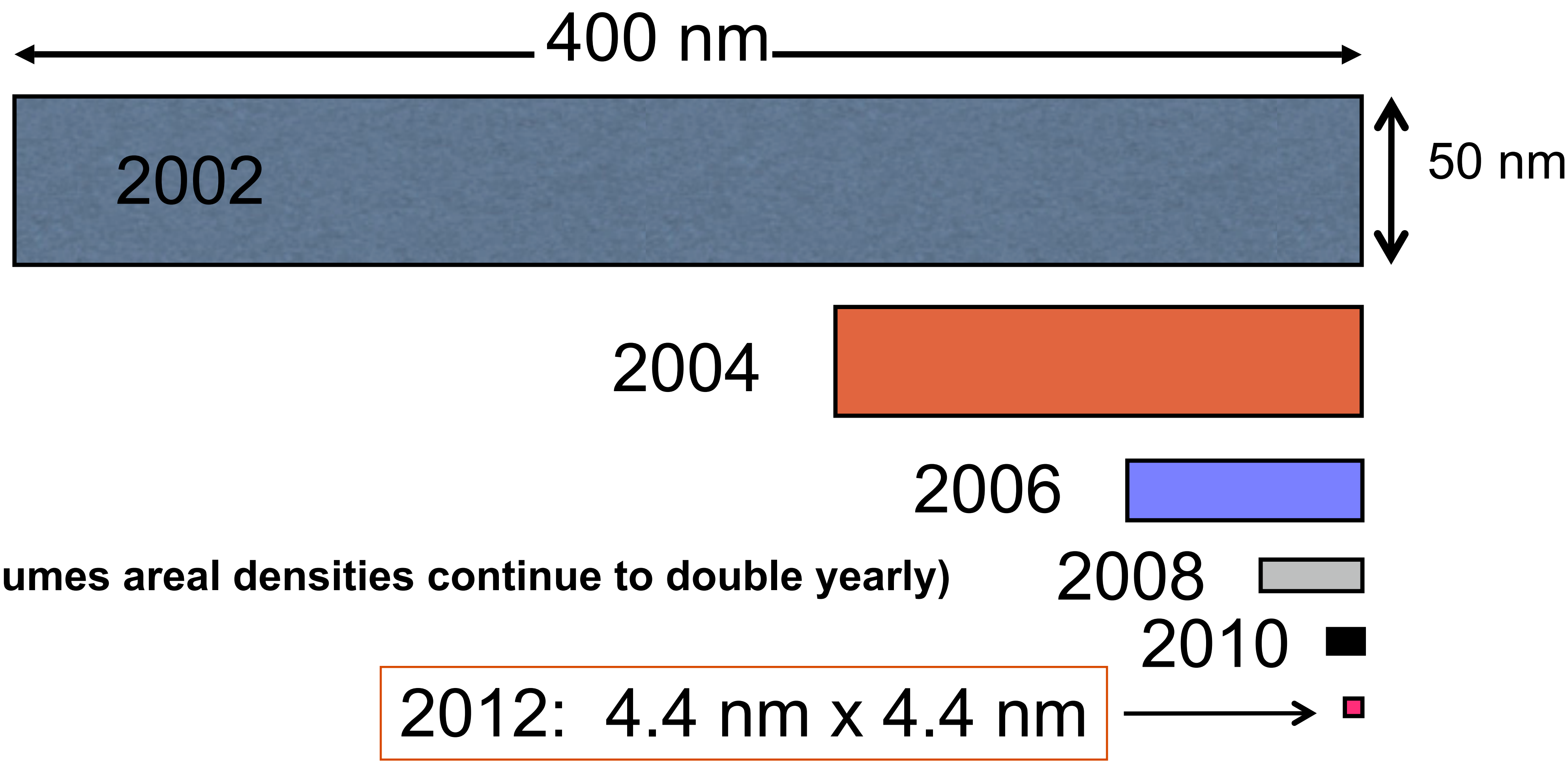


(assumes areal densities continue to double yearly)

this will probably not happen

50 TB per square inch on a quarter ...

- over 3.4 million high-resolution photos, or …
- 2,800 audio CDs, or…
- 1,600 hours of television, or …

50 TB per square inch on a quarter ...

- over 3.4 million high-resolution photos, or …
- 2,800 audio CDs, or…
- 1,600 hours of television, or …

- the entire printed collection of the U.S. Library of Congress

Library of Congress,
Jefferson building

so what's the problem?

at some point, they are no longer stable

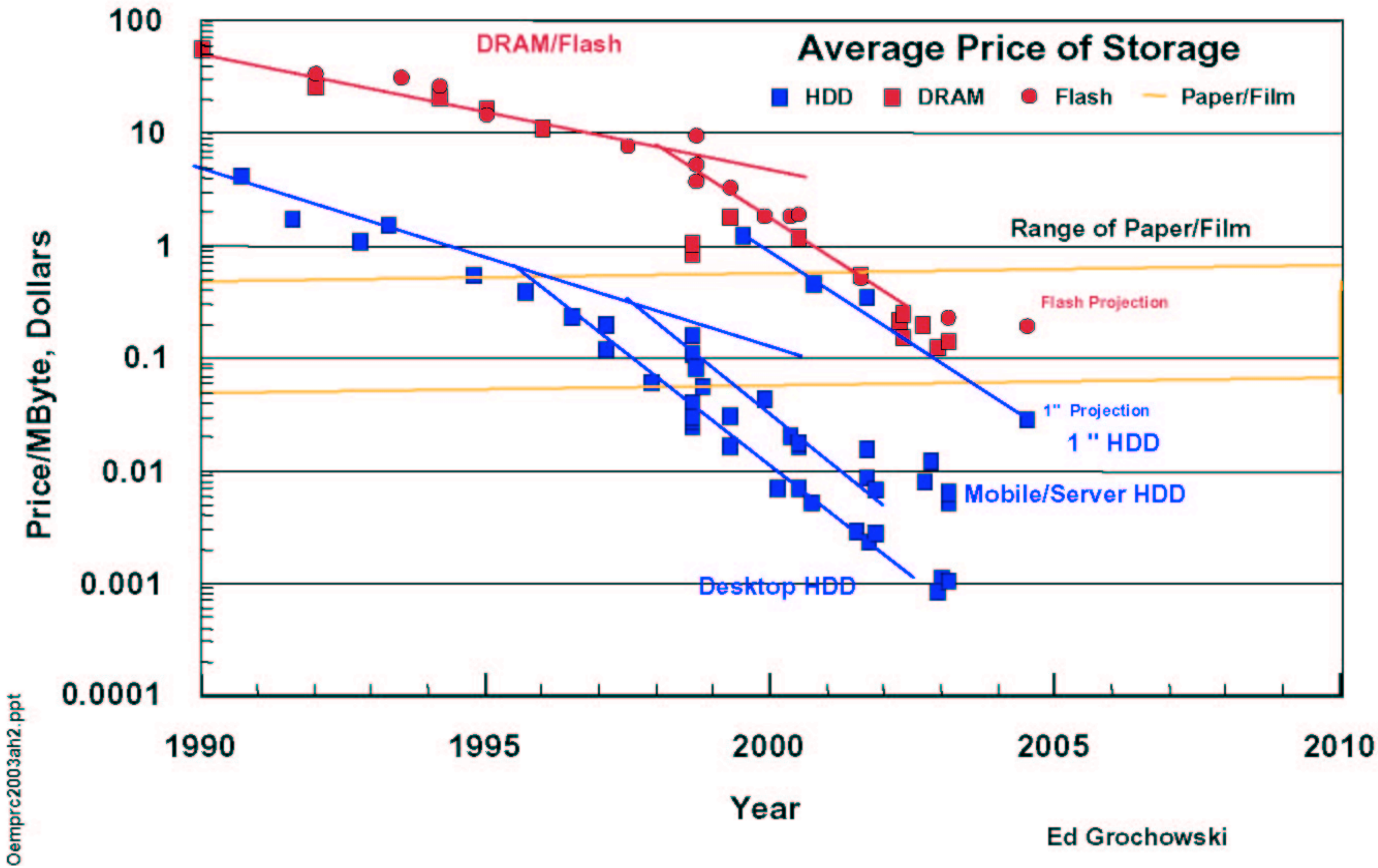
heat makes them 'wiggle'
    like drops of water on a griddle

bits are no longer reliable

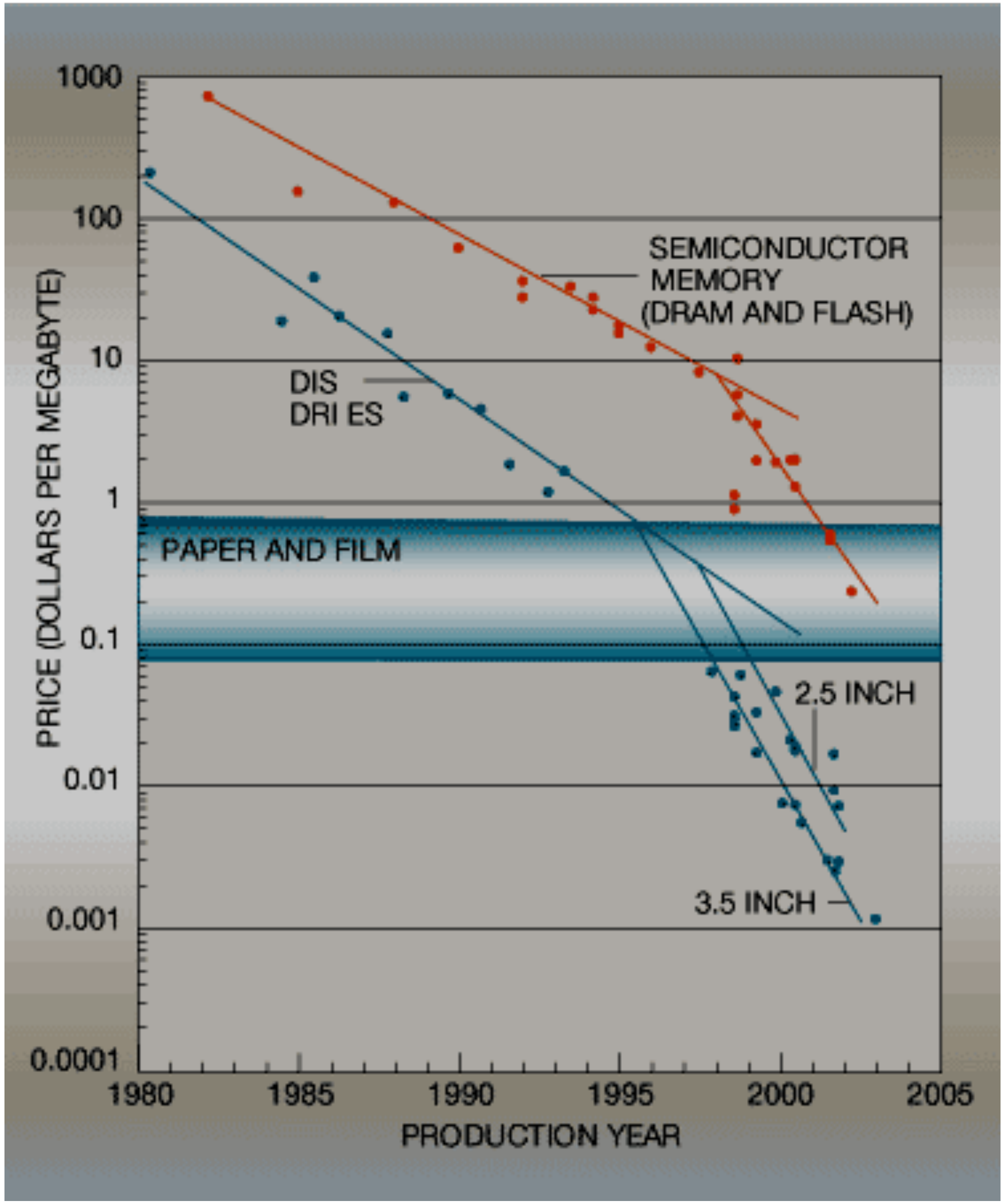
so we need stronger magnets ...
    ... which need more field to magnetize
    ... which needs more power

HUGE challenge in nanoscale materials science!

$$$ vs flash and DRAM

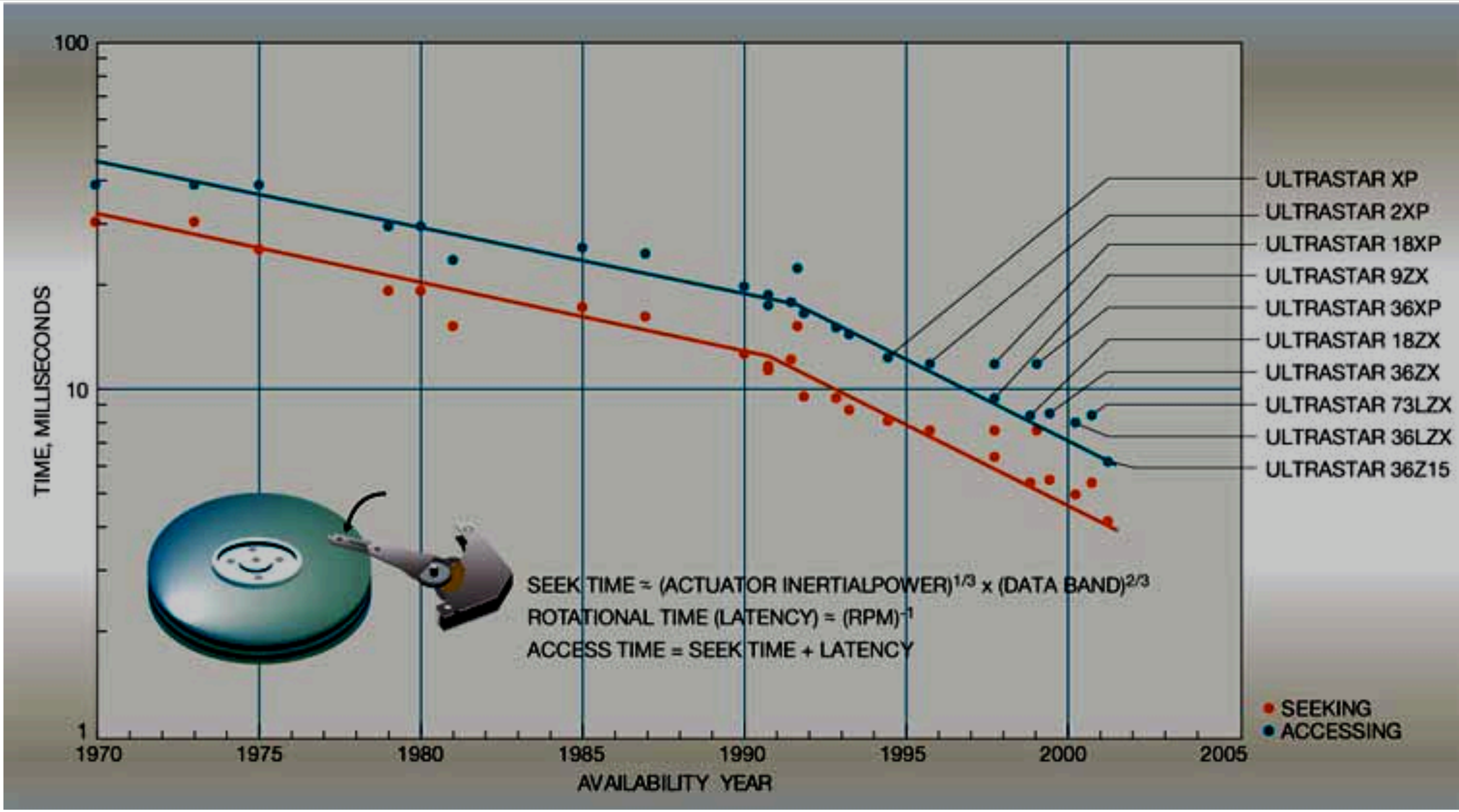


$$$ *vs* flash and DRAM



E. Grochowski and R.D. Halem
IBM Systems Journal, **42** (2), 2003

seek time



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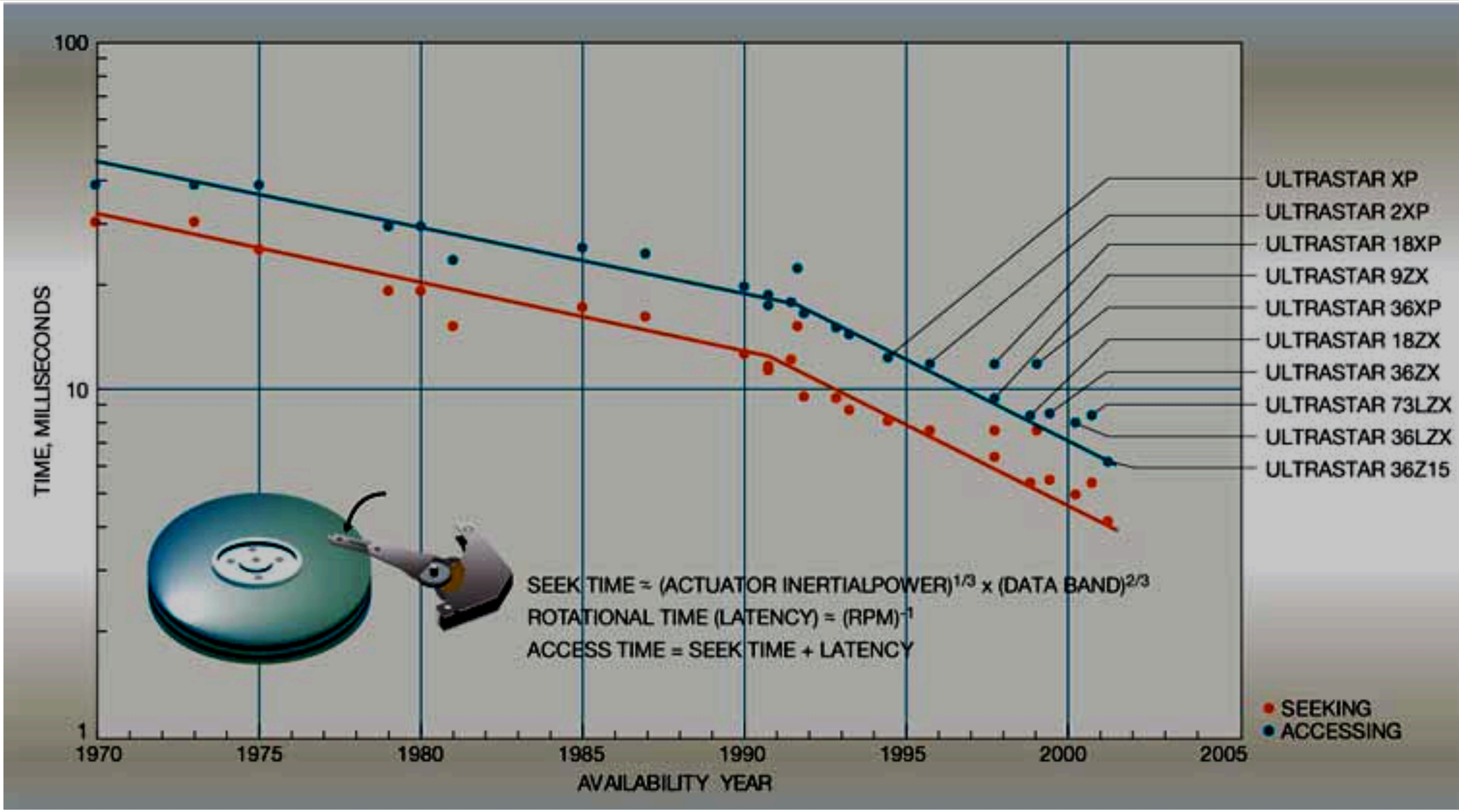

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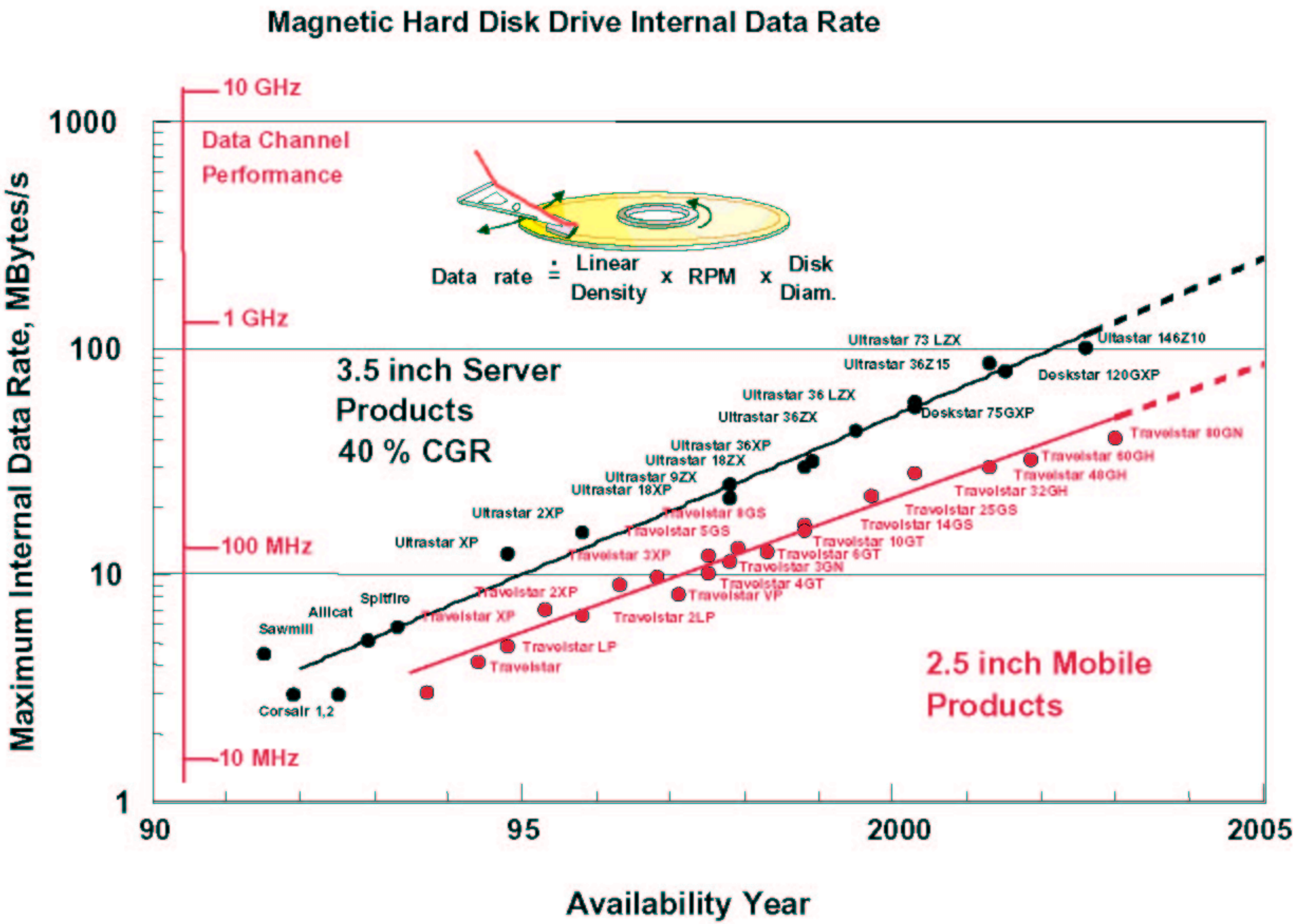
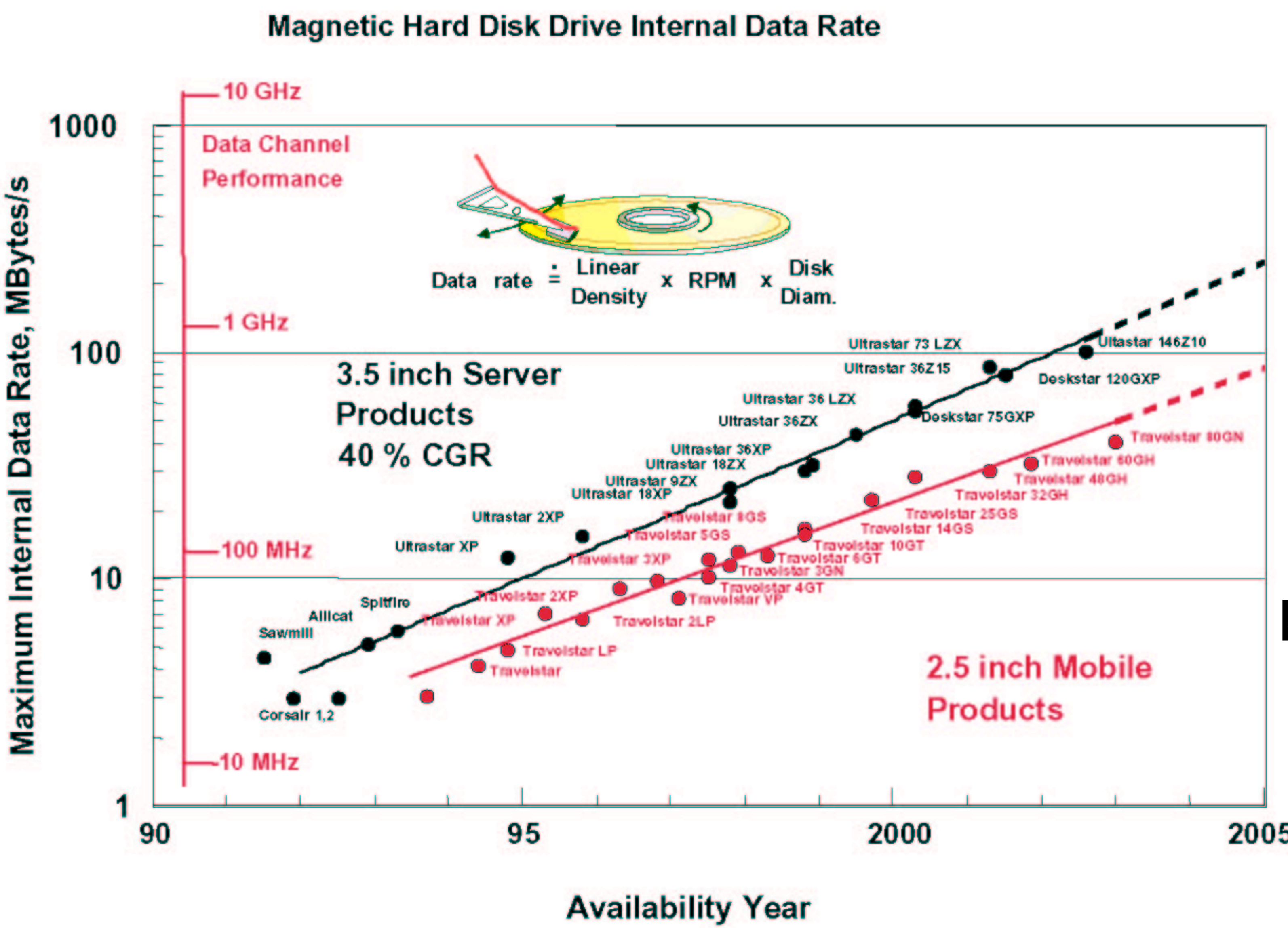
far higher than DRAM/SRAM (~nsec)
reduction limited by mechanics!

throughput



Magnetic Hard Disk Drive Internal Data Rate
Maximum Internal Data Rate, MBytes/s
Availability Year
1000
100
10
1
90
95
2000
2005
10 GHz
1 GHz
100 MHz
10 MHz
Data Channel Performance
Data rate = Linear Density x RPM x Disk Diam.
3.5 inch Server Products
40 % CGR
2.5 inch Mobile Products
Sawmill
Corsair 1,2
Allicat
Spitfire
Ultrastar XP
Ultrastar 2XP
Ultrastar 18XP
Ultrastar 9ZX
Ultrastar 18ZX
Ultrastar 36XP
Ultrastar 36ZX
Ultrastar 36 LZX
Ultrastar 36Z15
Ultrastar 73 LZX
Ultastar 146Z10
Deskstar 120GXP
Deskstar 75GXP
Travelstar
Travelstar LP
Travelstar XP
Travelstar 2XP
Travelstar 2LP
Travelstar 3XP
Travelstar 5GS
Travelstar 8GS
Travelstar VP
Travelstar 4GT
Travelstar 3GN
Travelstar 6GT
Travelstar 10GT
Travelstar 14GS
Travelstar 25GS
Travelstar 32GH
Travelstar 48GH
Travelstar 60GH
Travelstar 80GN

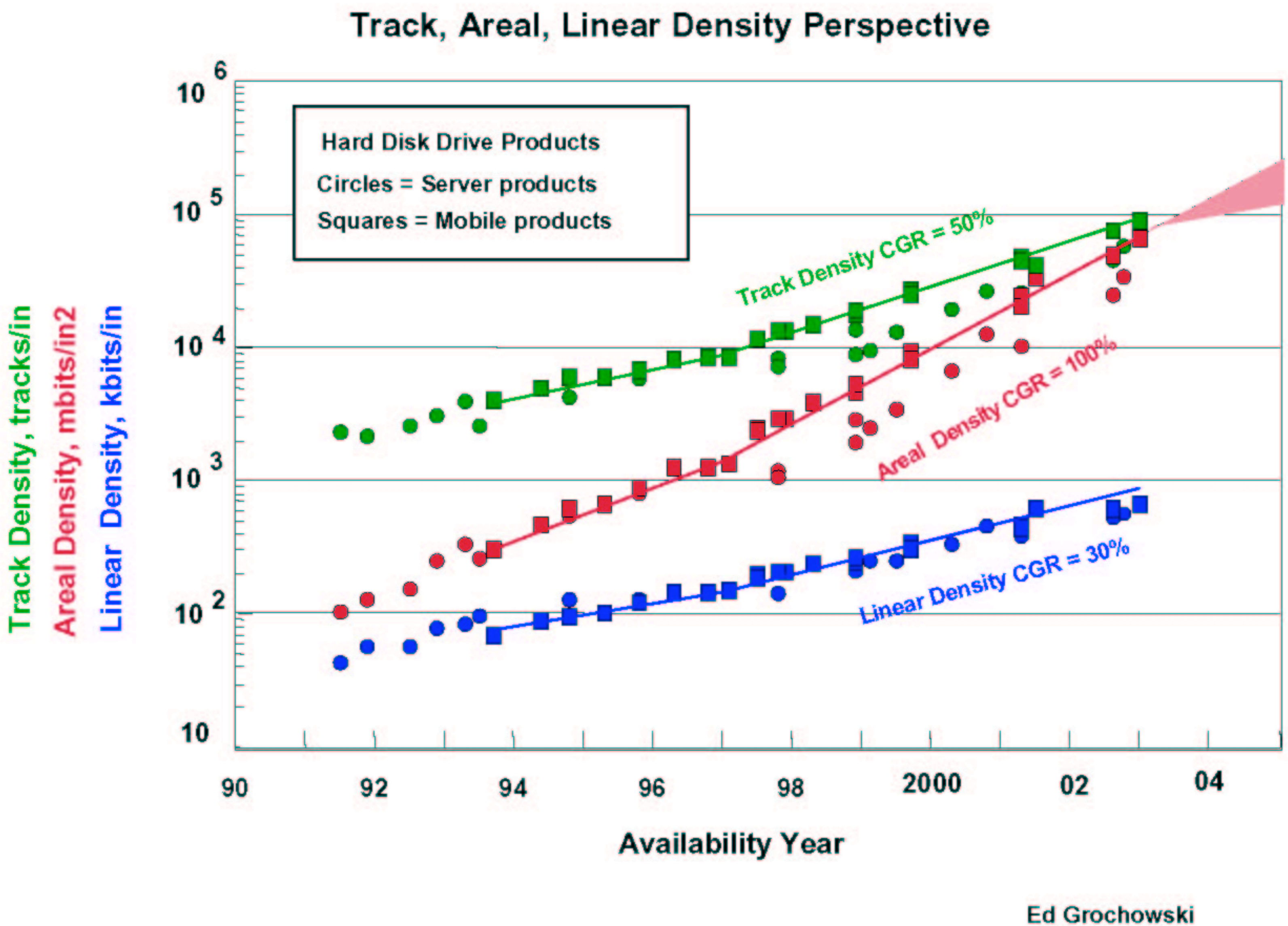
throughput



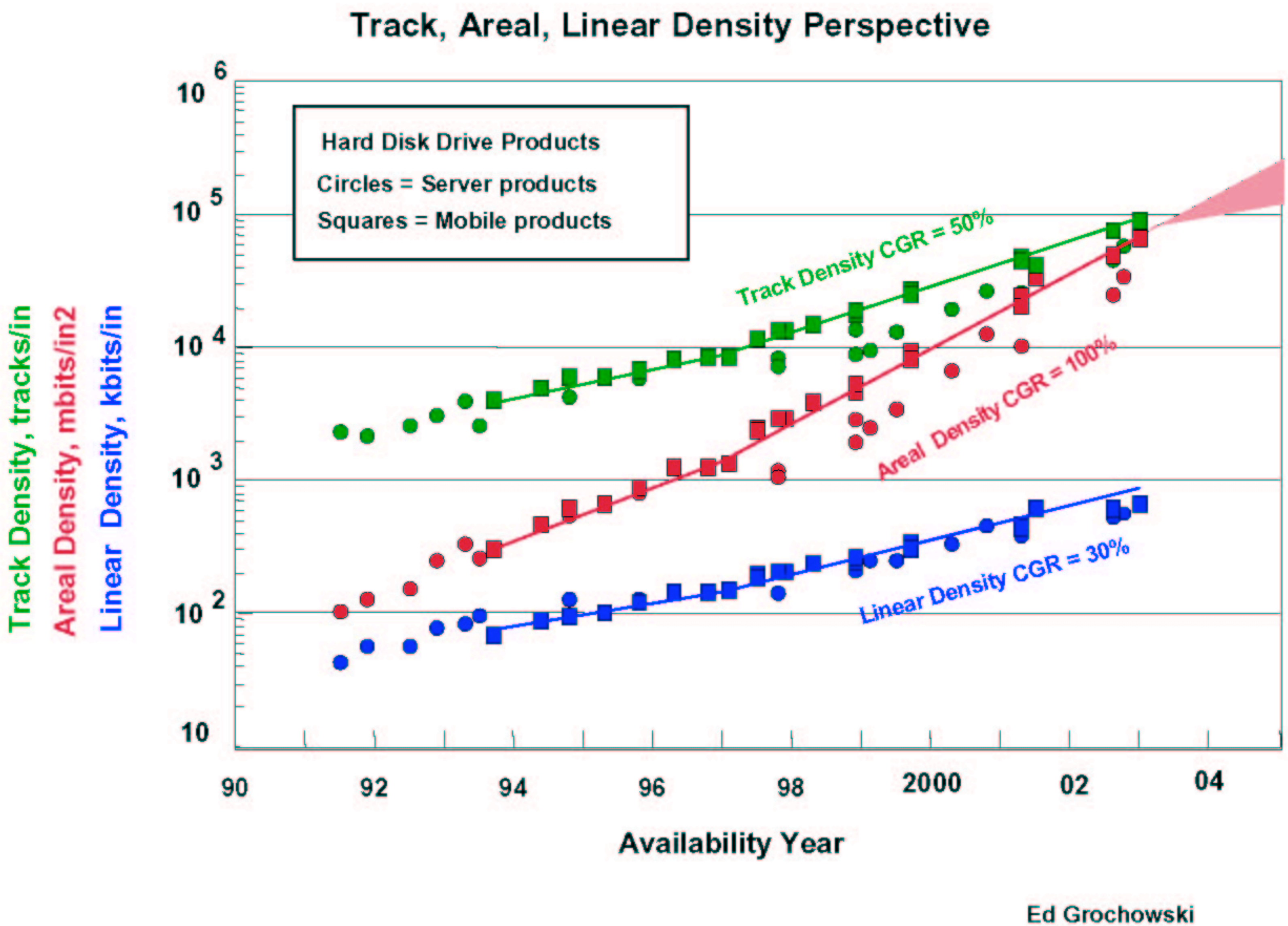
areal density growing *faster* than data rate

problem, or no?

density metrics

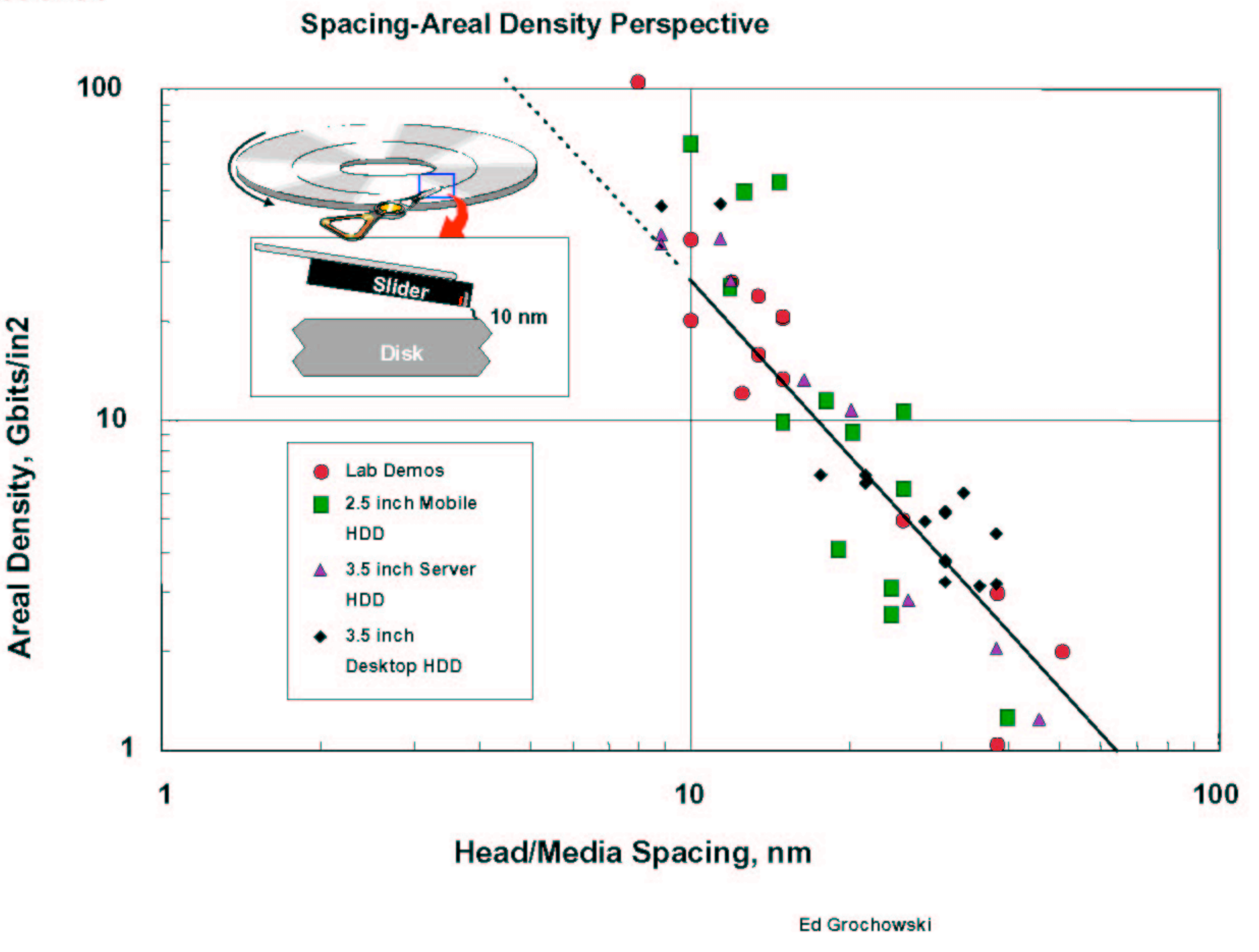


density metrics



this is why we quote *areal* density.

head-media spacing



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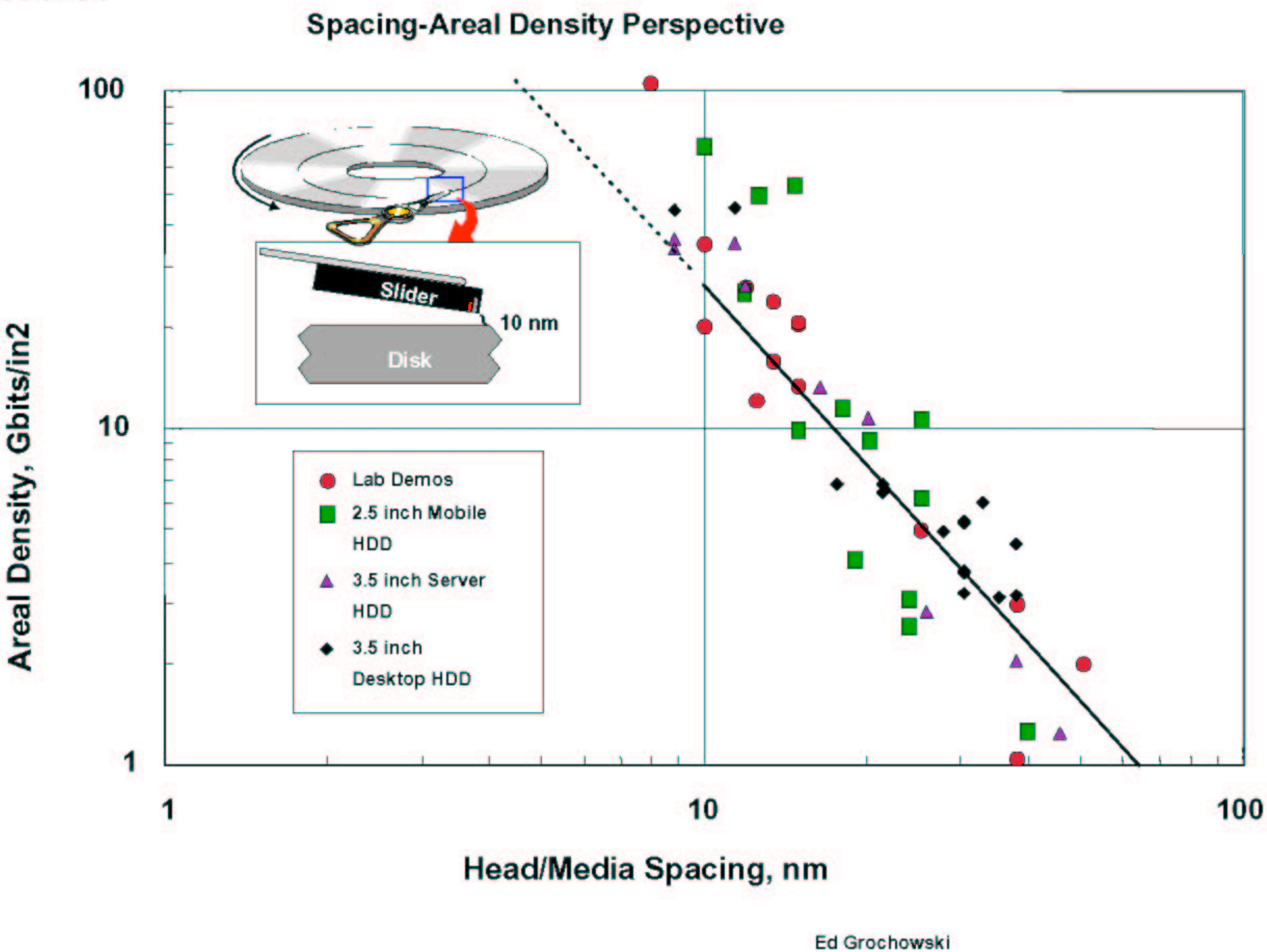
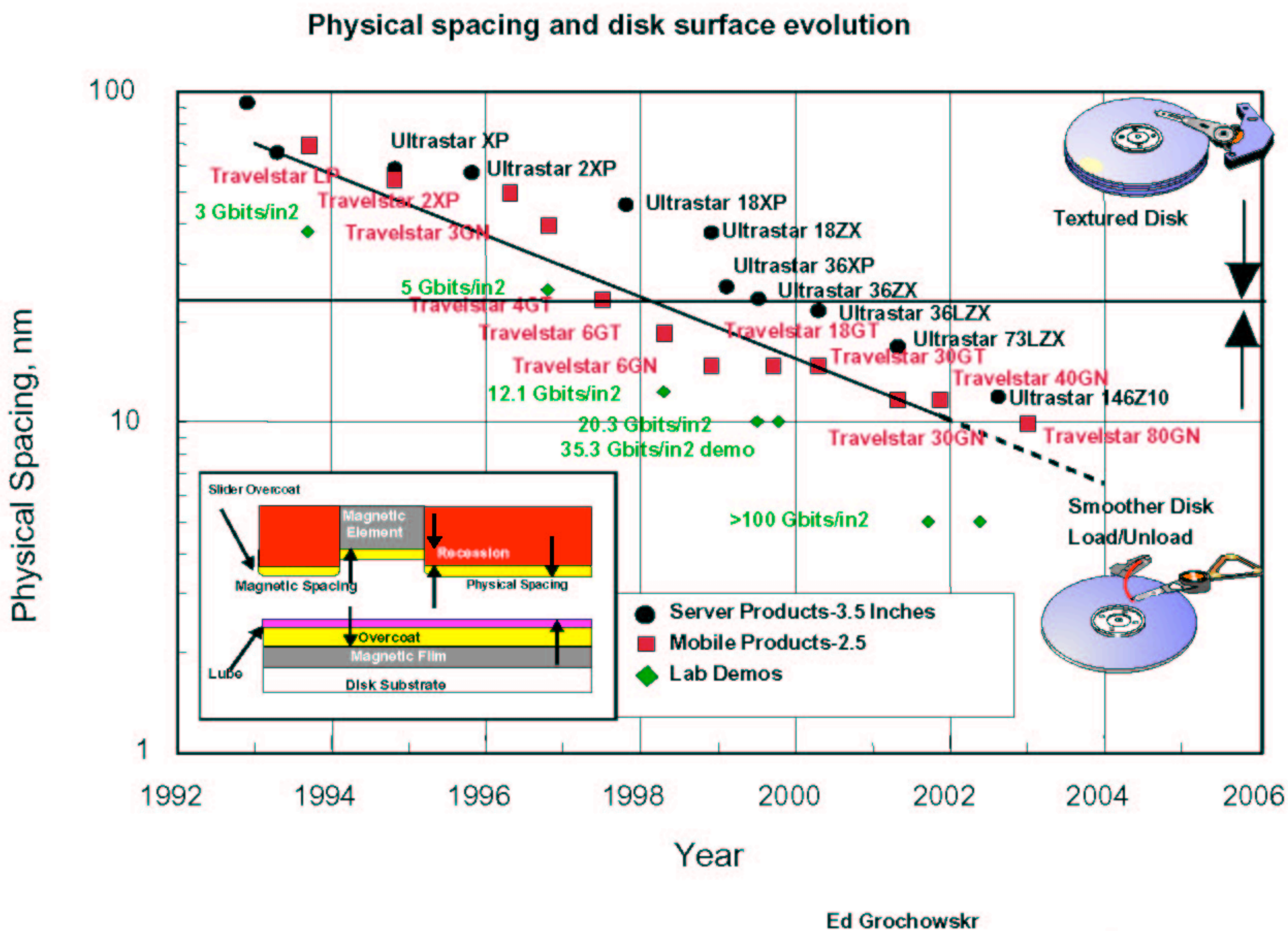


tribology ...

we are basically in contact

physical spacing



competition?

	SRAM	DRAM	Flash	FeRAM	MRAM	PCRAM
Read speed	Fastest	Medium	Fast	Fast	Fast	Fast
Write speed	Fastest	Medium	Slow	Medium	Fast	Medium
Array efficiency	High	High	Medium/low	Medium	Medium/high	Medium/high
Future scalability	Good	Limited	Limited	Limited	Good	Good
Cell density	Low	High	High	Medium	Medium/high	Medium/high
Nonvolatility	No	No	Yes	Yes	Yes	Yes
Endurance	Infinite	Infinite	Limited	Limited	Infinite	Infinite
Cell leakage	Increasing	High	Low	Low	Low	Low
Low voltage	Yes	Limited	Limited	Limited	Yes	Yes
Complexity	Low	Medium	Medium	Medium	Medium	Medium

competition?

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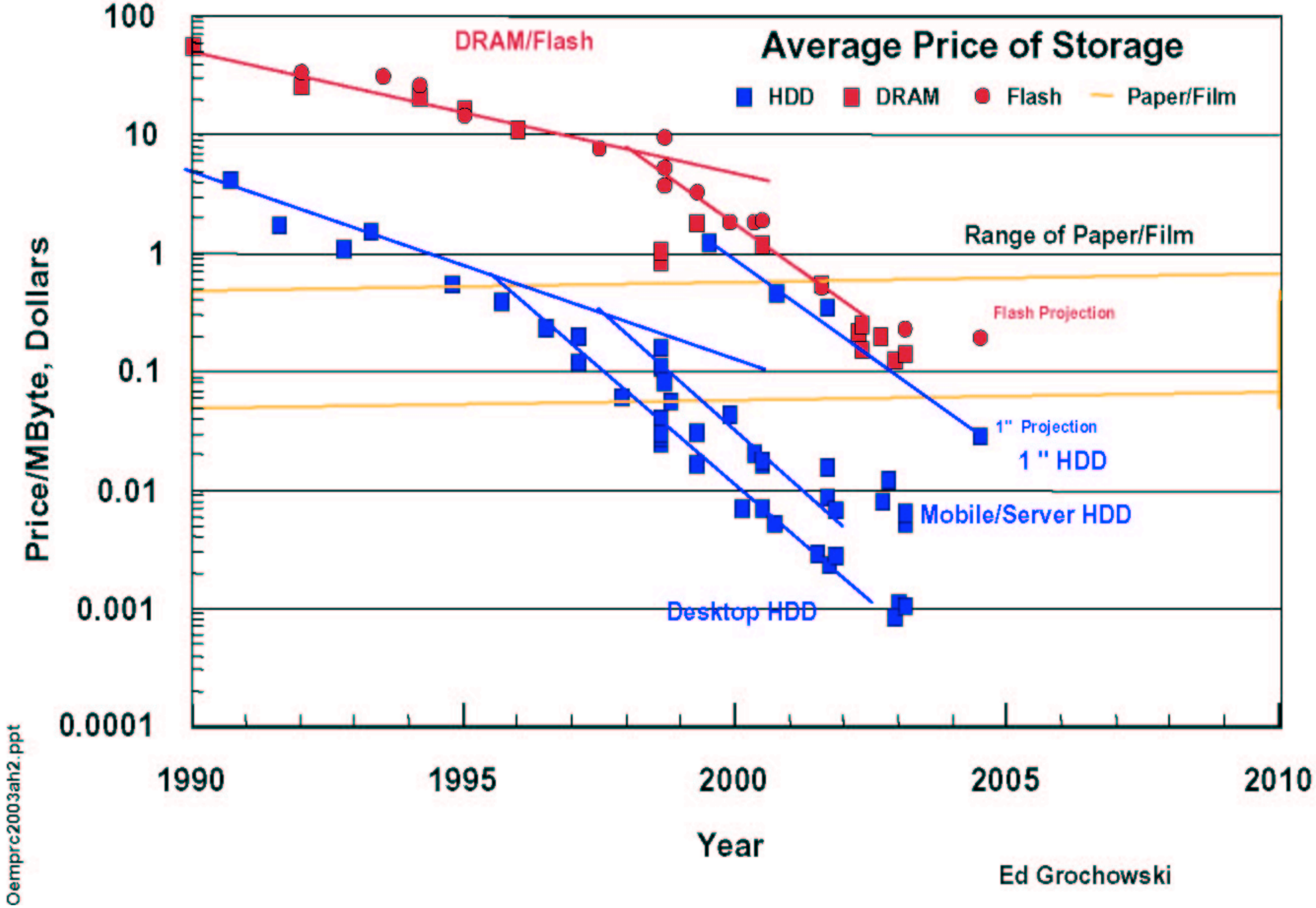
price is our real advantage.



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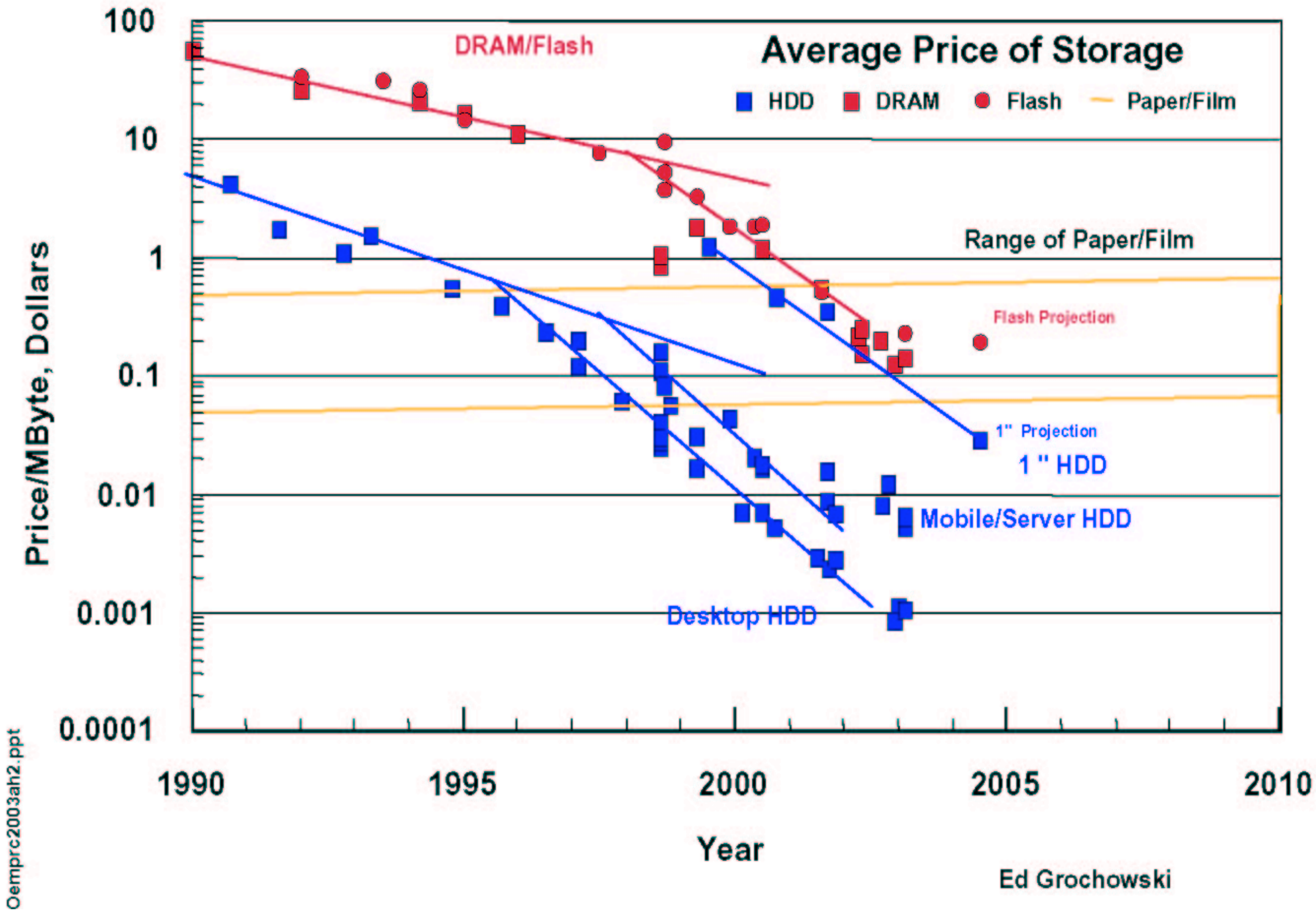

flash is beating the 1" HDD in some apps

e.g., mp3, camera

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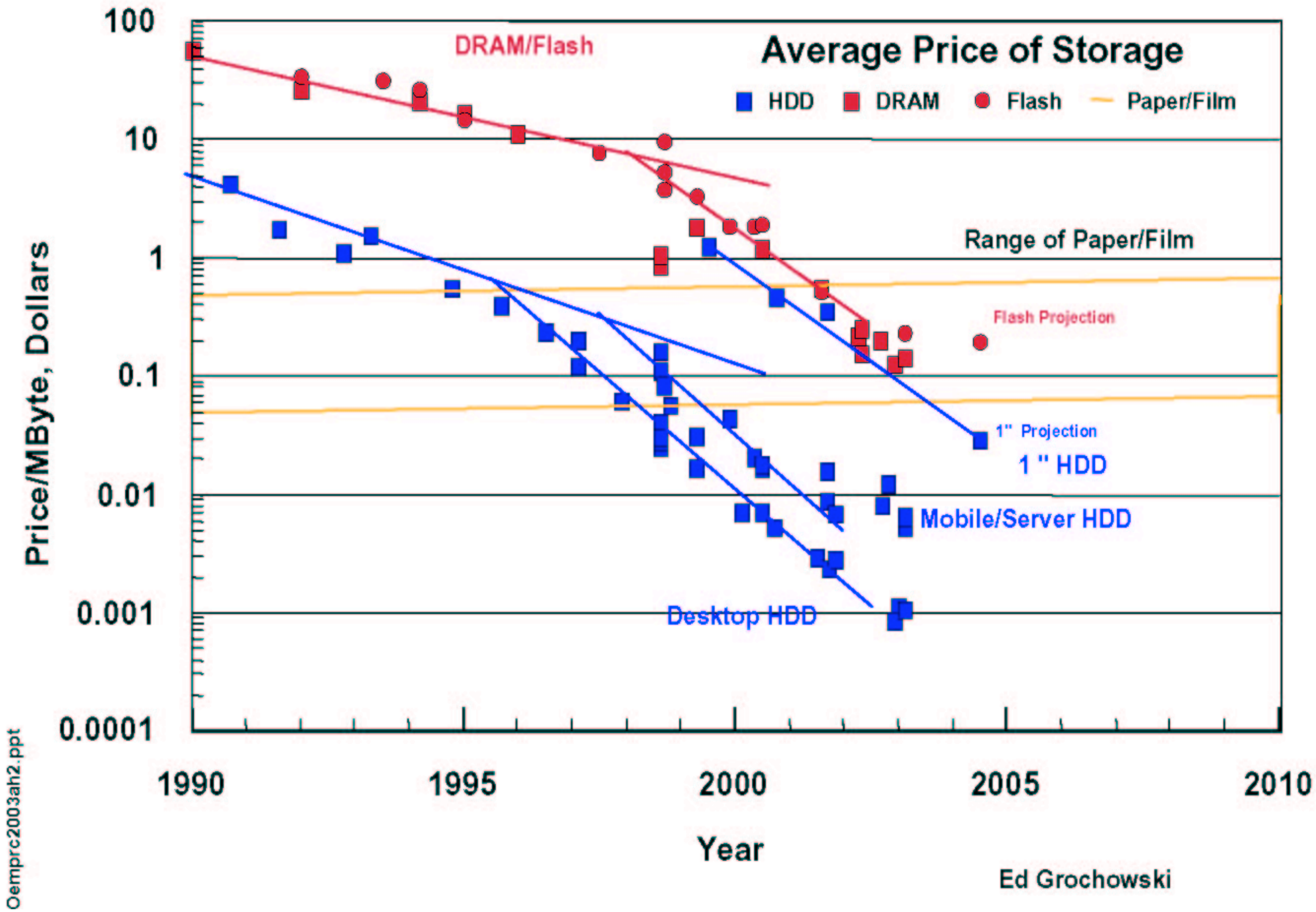

flash is beating the 1" HDD in some apps

e.g., mp3, camera

power consumption may be the larger issue

power consumption is not an advantage

latency ...

fundamental limits of magnetism?

power consumption is not an advantage

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fundamental limits of magnetism?

more importantly ...

power consumption is not an advantage

latency ...

fundamental limits of magnetism?

more importantly ...
will we get "scooped" like bubbles?

SO!

before we get into alternatives ...

how does what we have work?

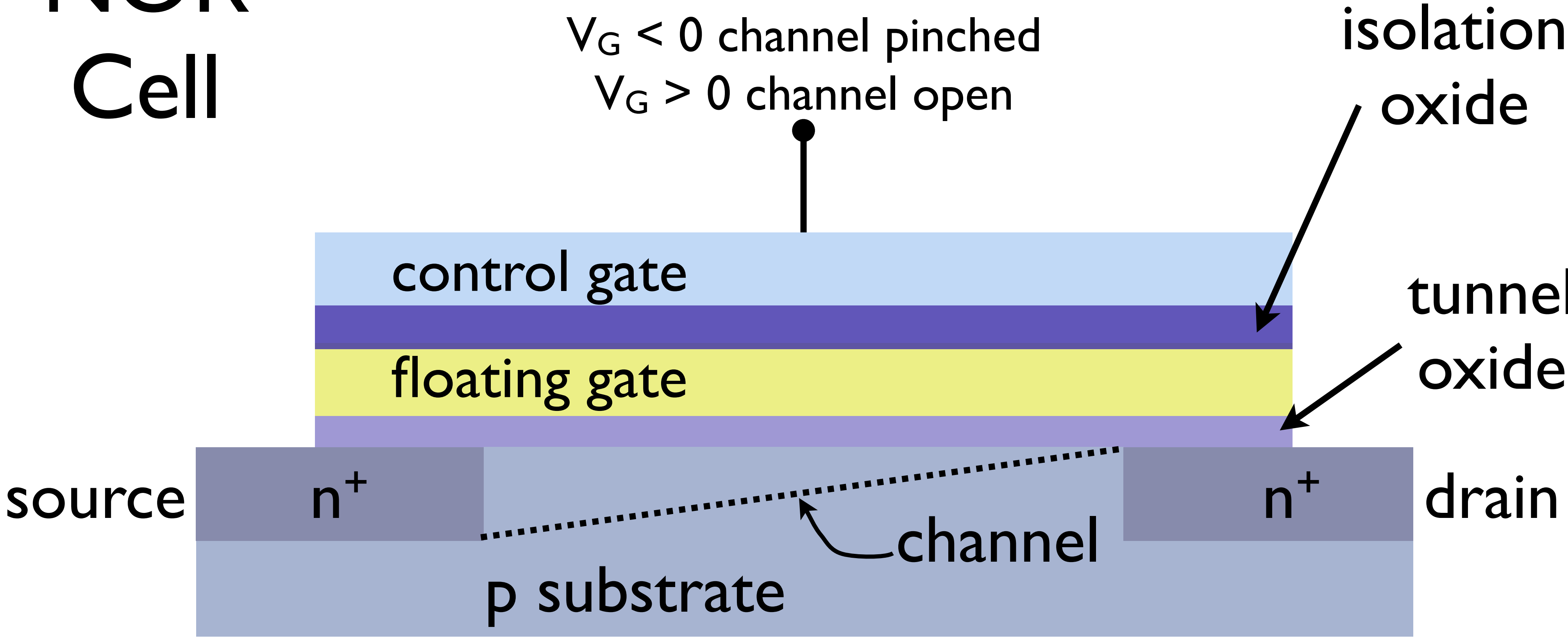
SO!

before we get into magnetic recording details ...

how does flash work?

the basics of Flash

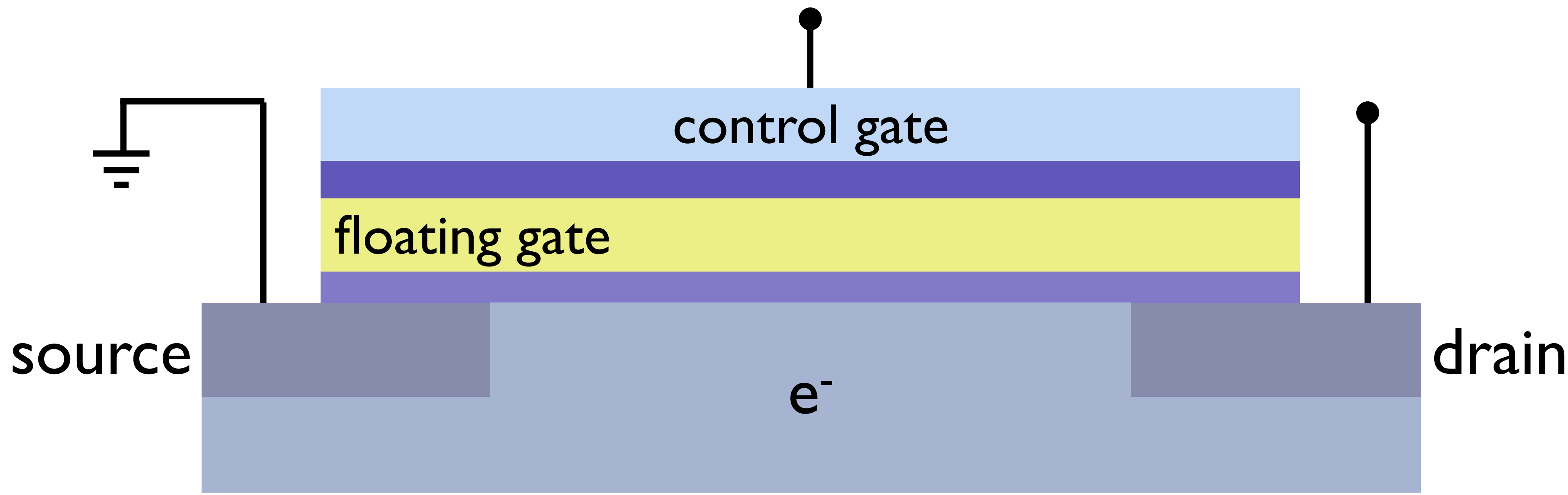
NOR Cell



- like a MOSFET
- uses 2 gates

writing

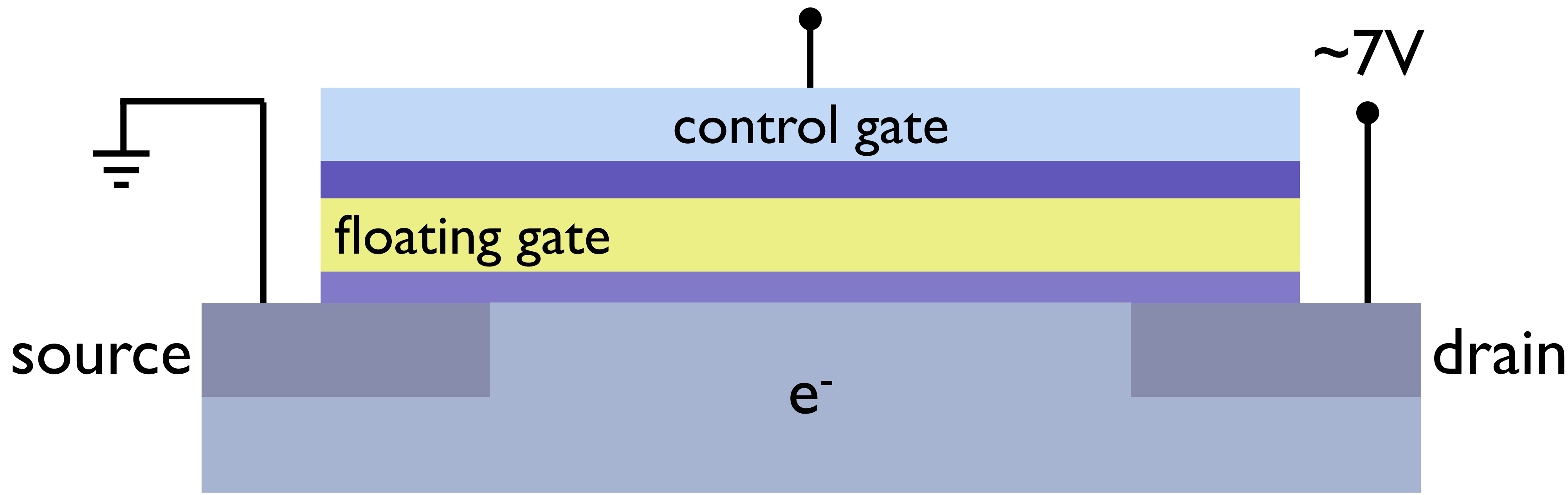
"hot electron injection"



- ~7V to drain
  pull e⁻ through channel
- ~12V to control gate / open channel
  injects e⁻ into floating gate through tunnel oxide
- floating gate now charged

writing

"hot electron injection"



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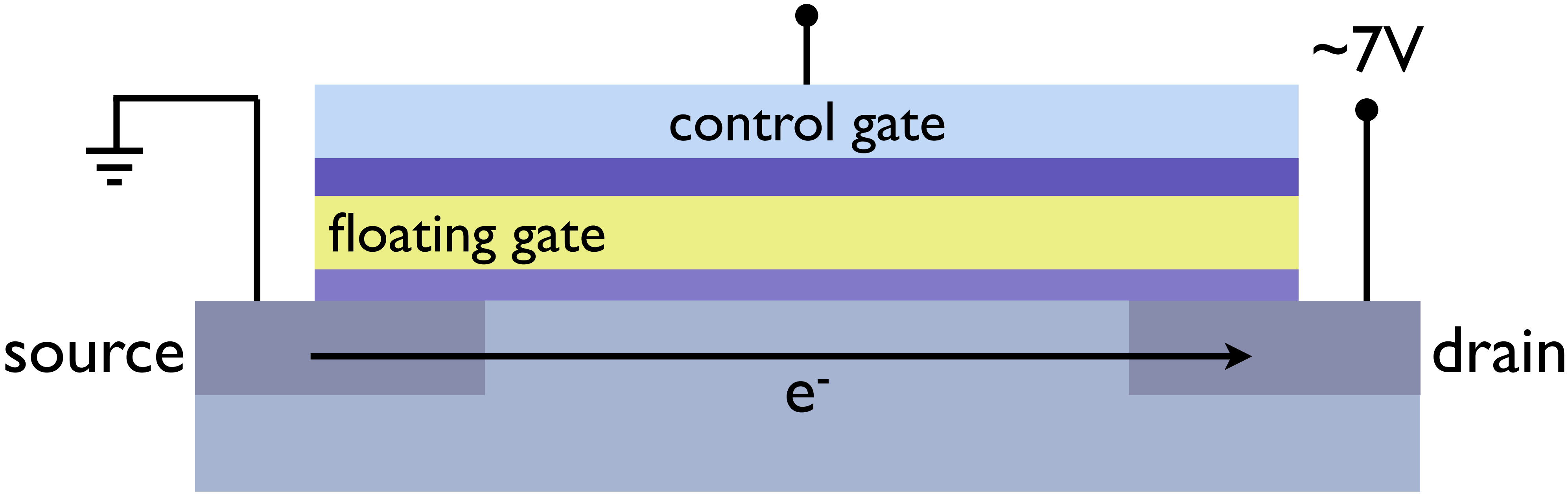

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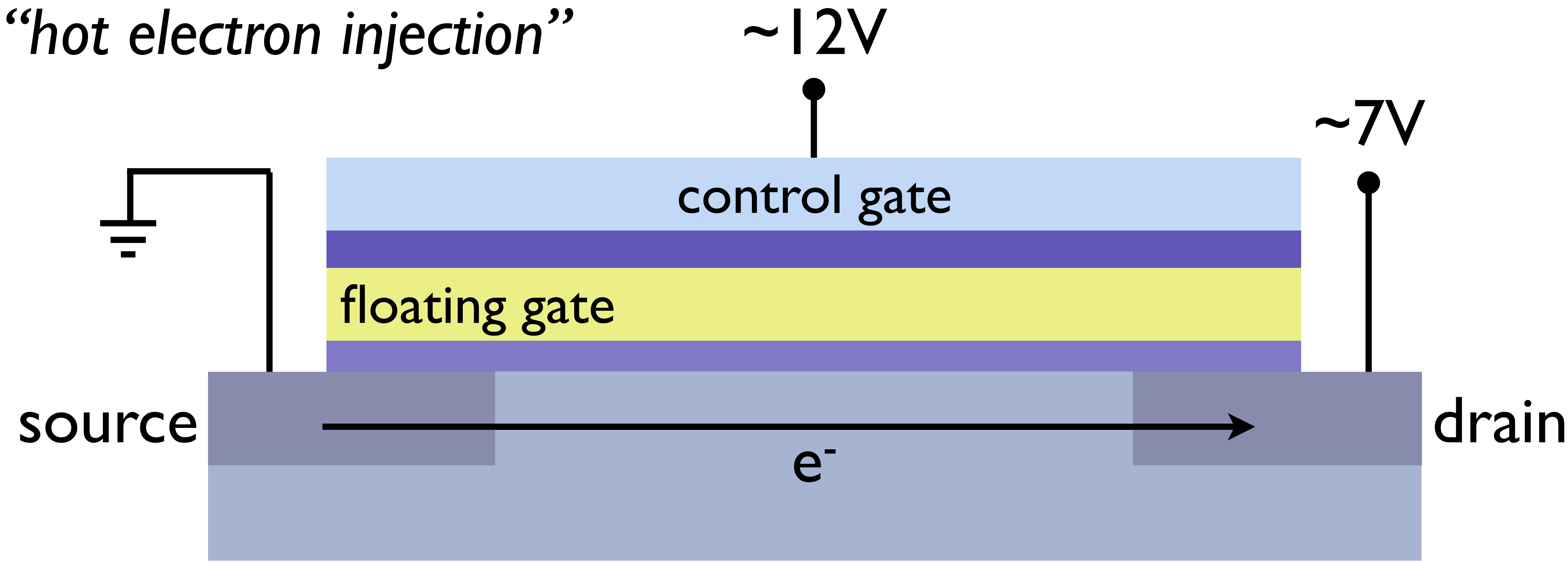

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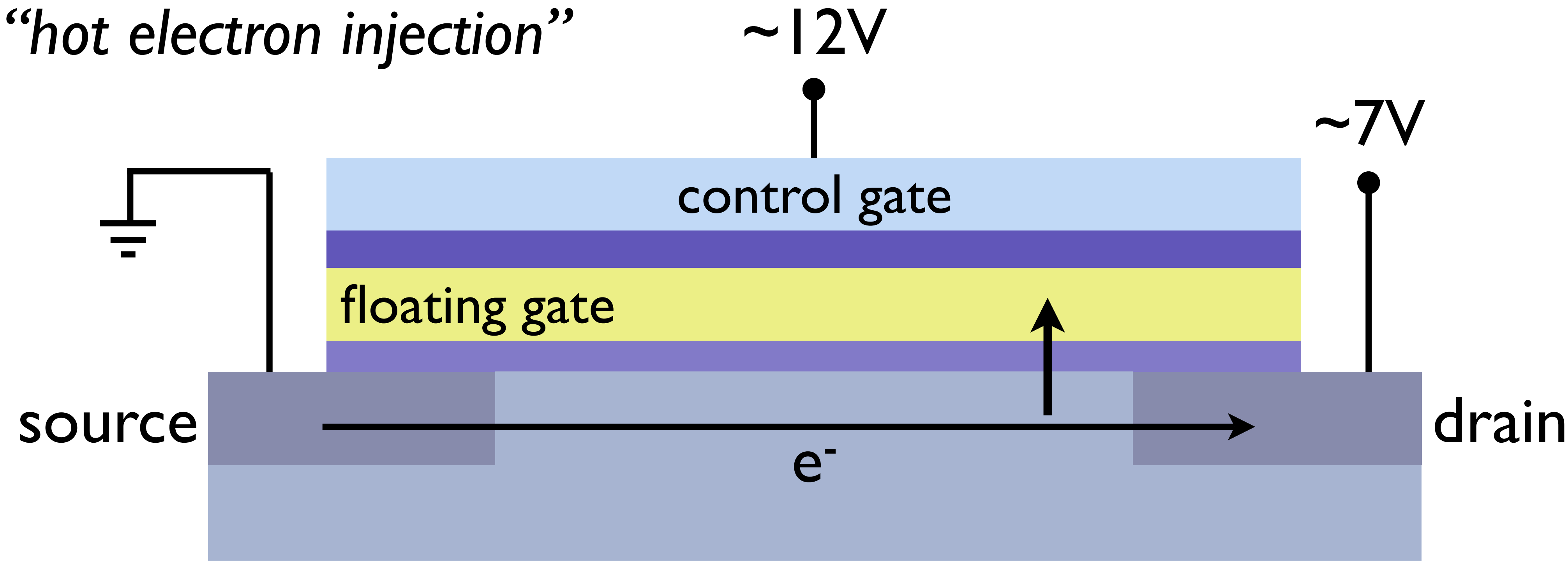

- ~7V to drain
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- ~12V to control gate / open channel
  injects e- into floating gate through tunnel oxide
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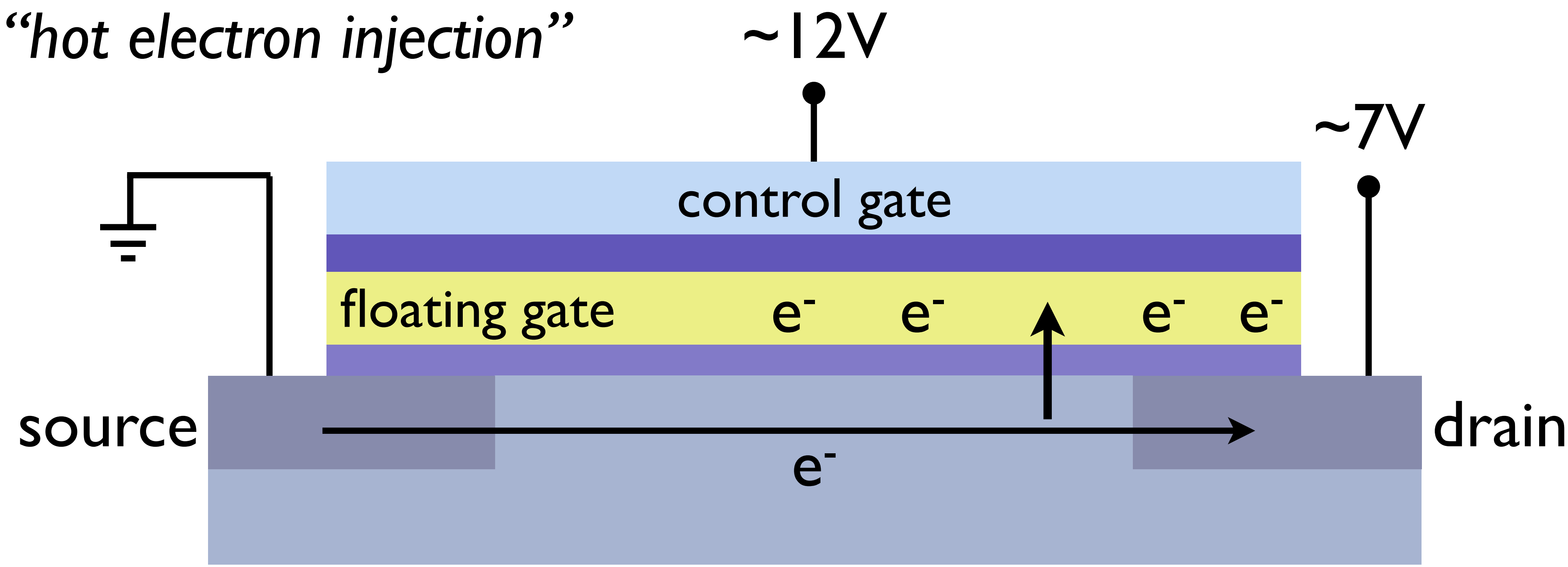
writing



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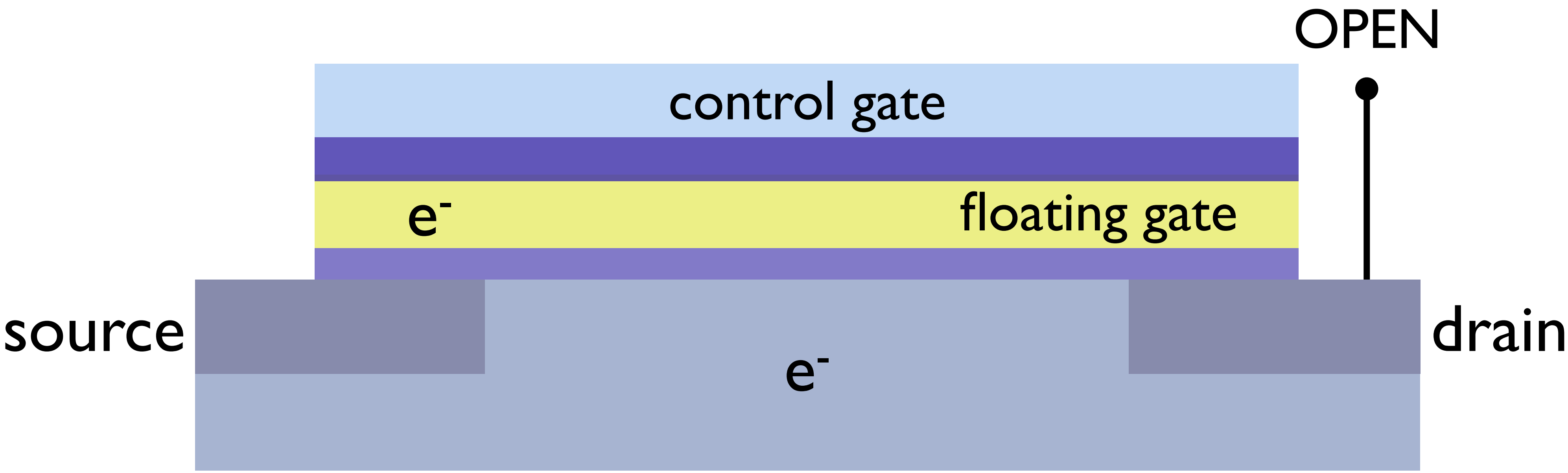
- floating gate now charged

erasing

reset all bits to "1"



- -9V to control
  - pinch off channel
- ~6V to source
- suck electrons out of floating gate into source
  - Fowler-Nordheim tunneling

erasing

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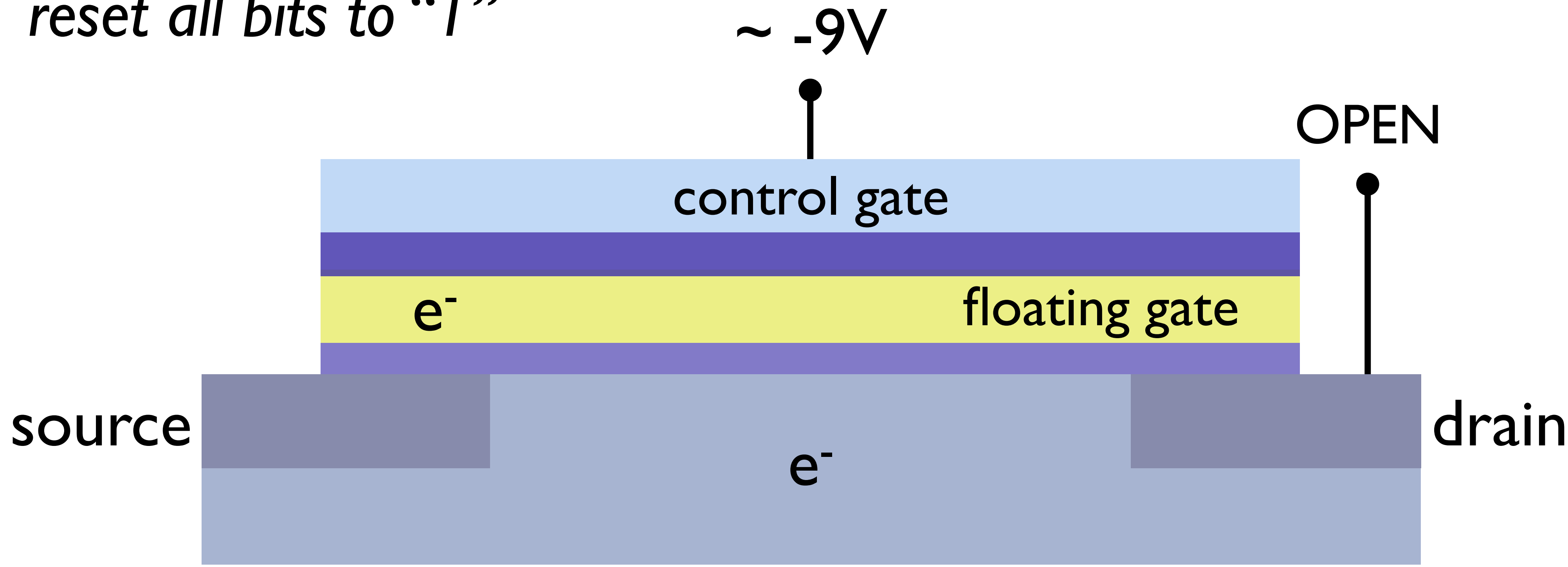

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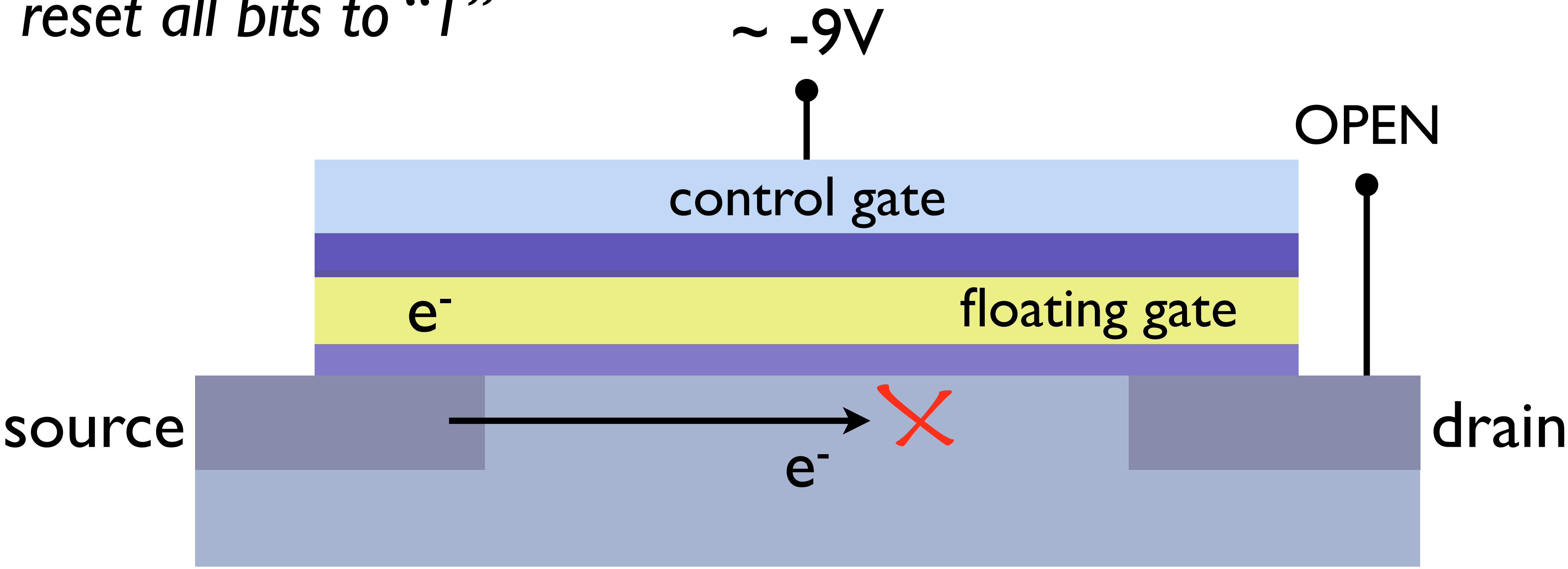

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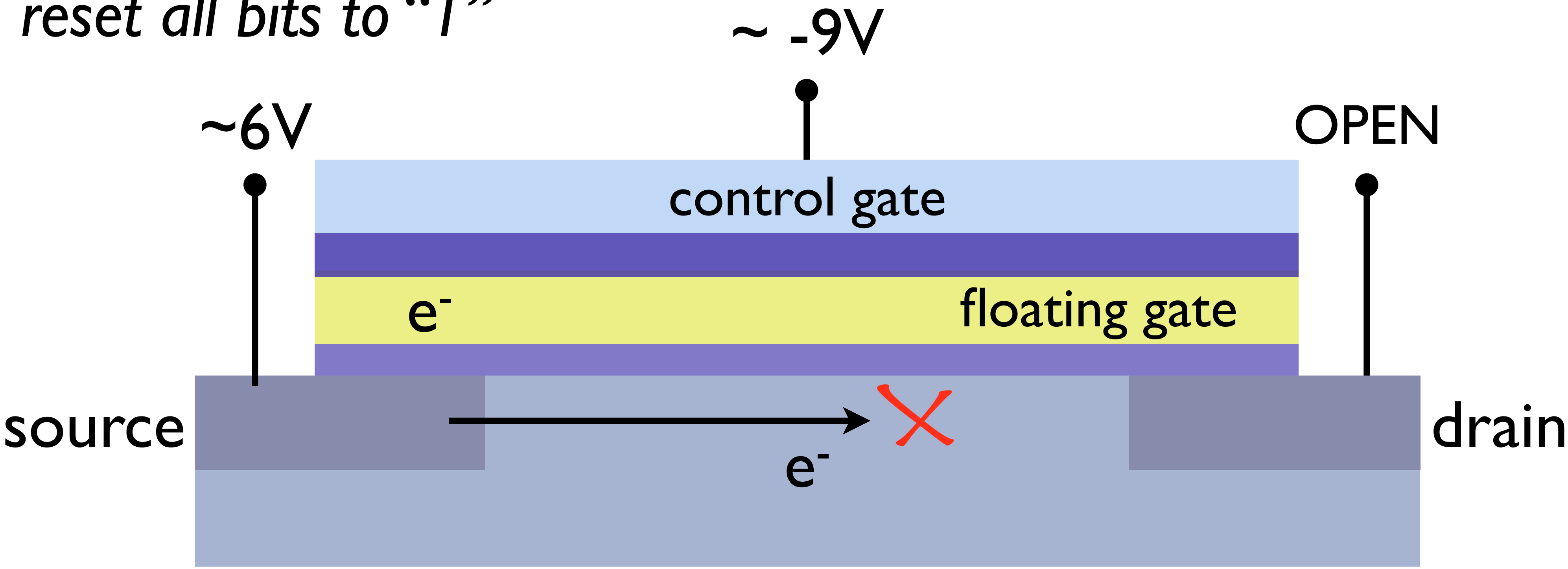

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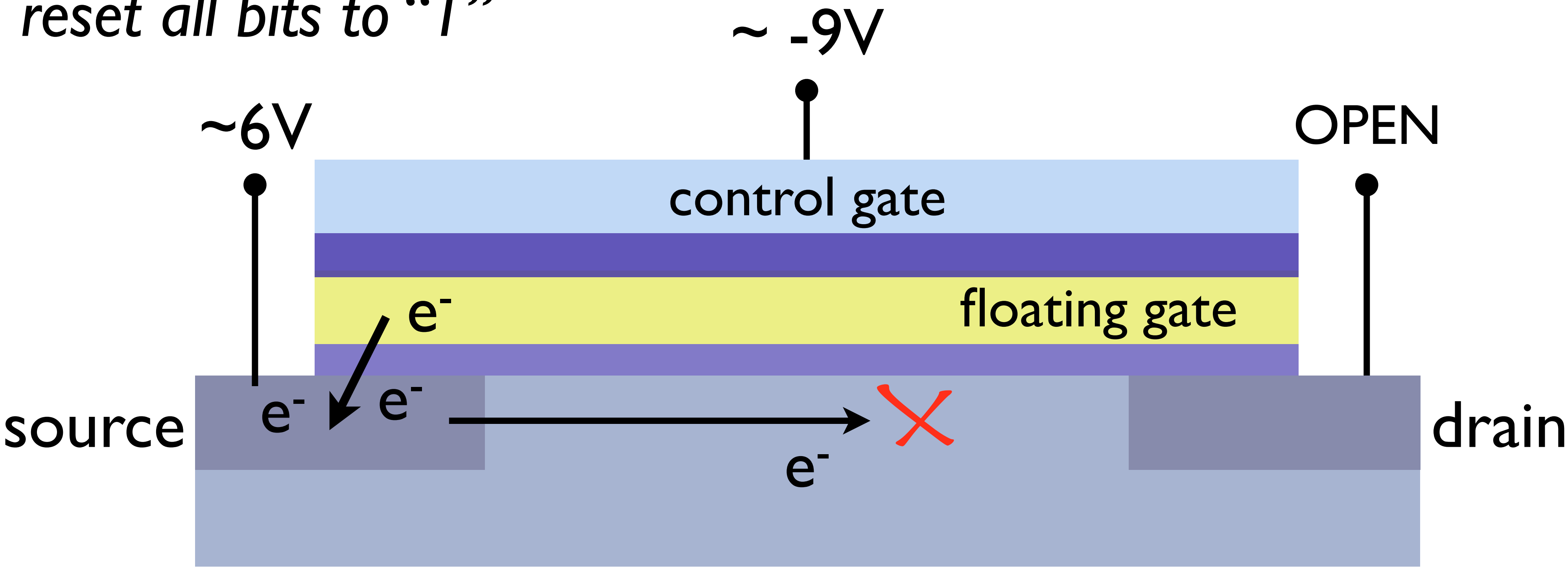

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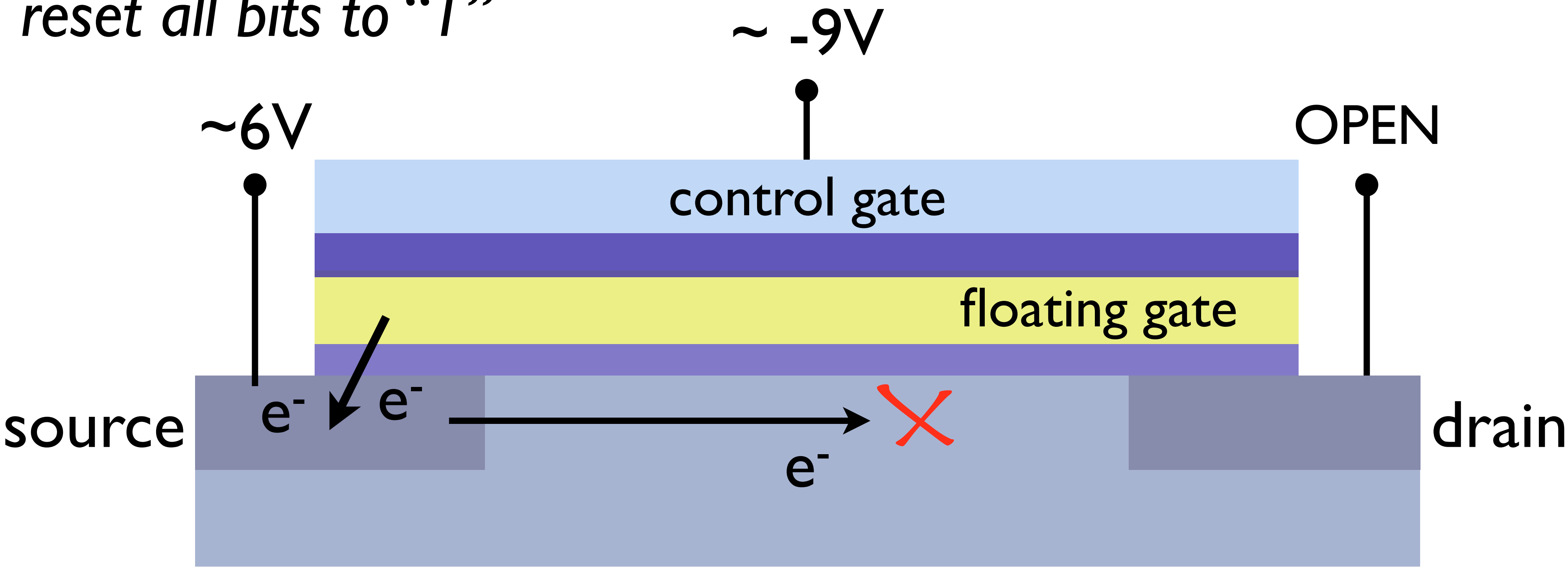

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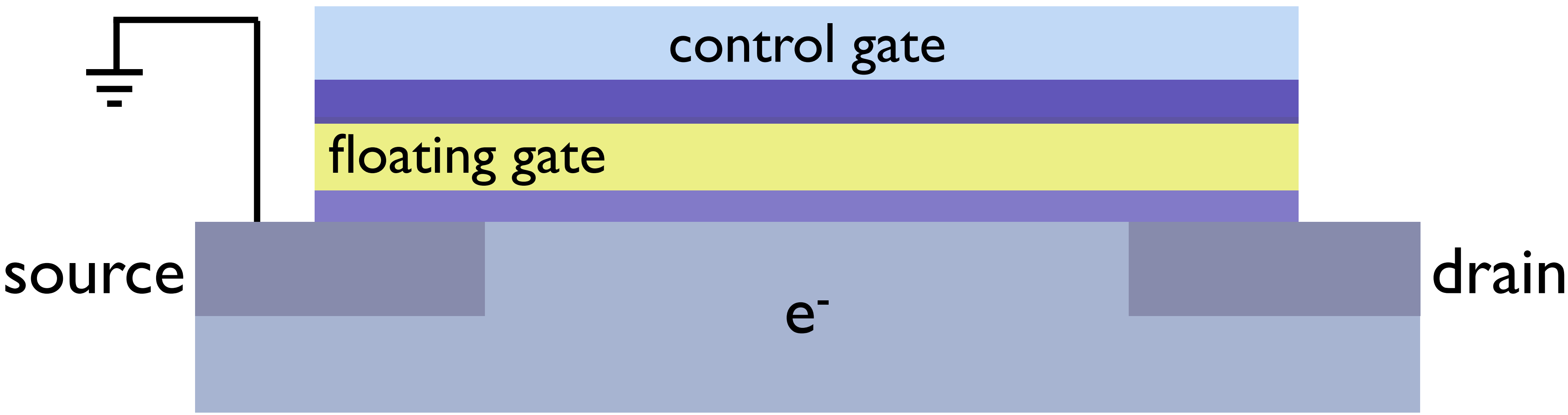

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- 1V to drain
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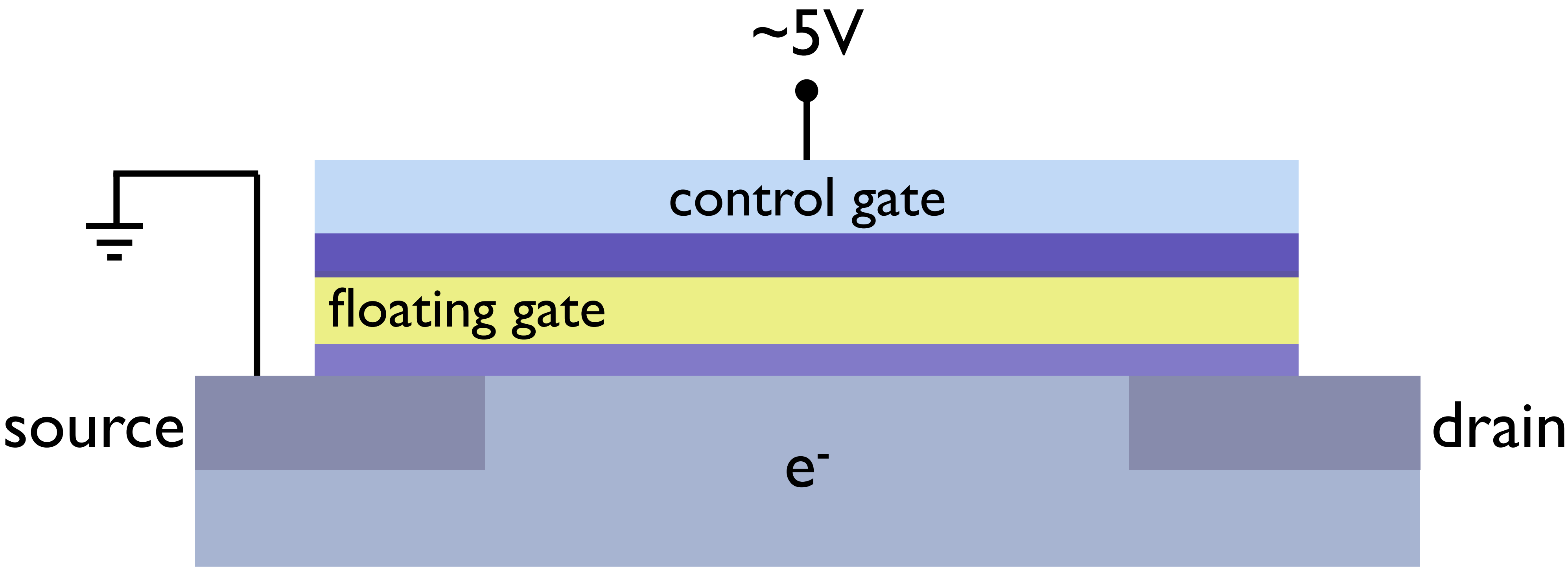
- floating gate *discharged* = channel open = "1"

presence of charge modulates I_{SD} !

reading



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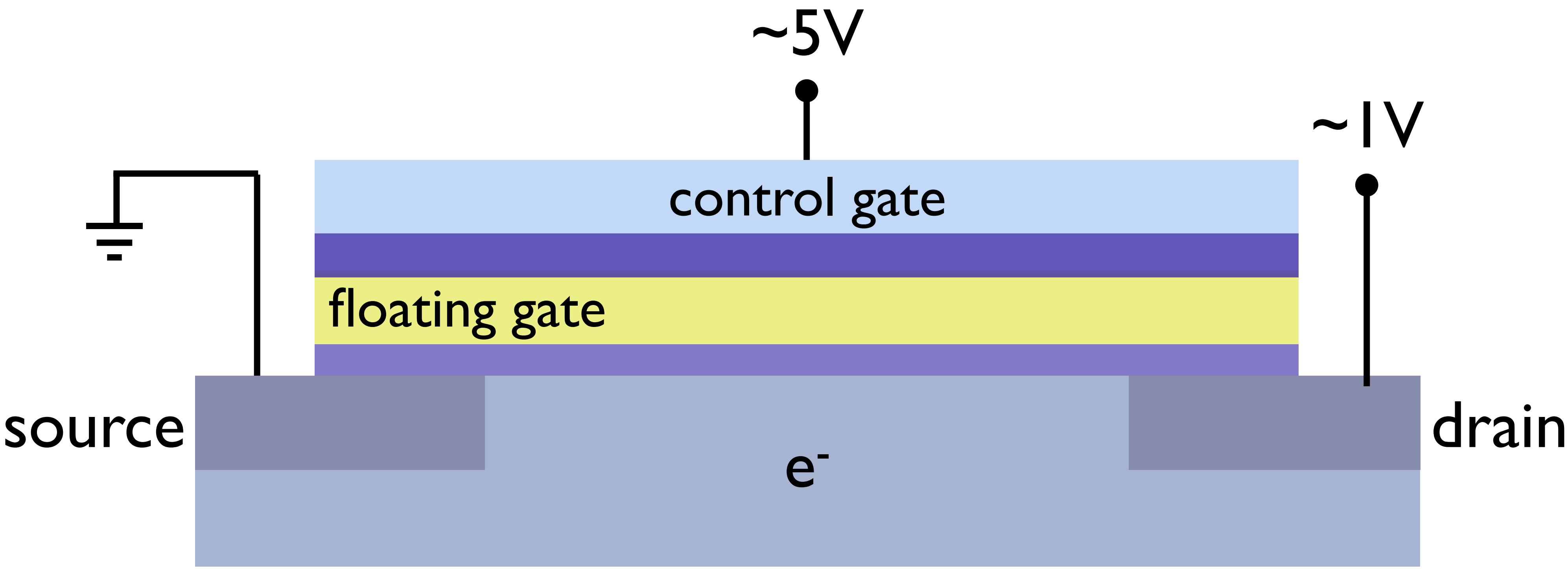

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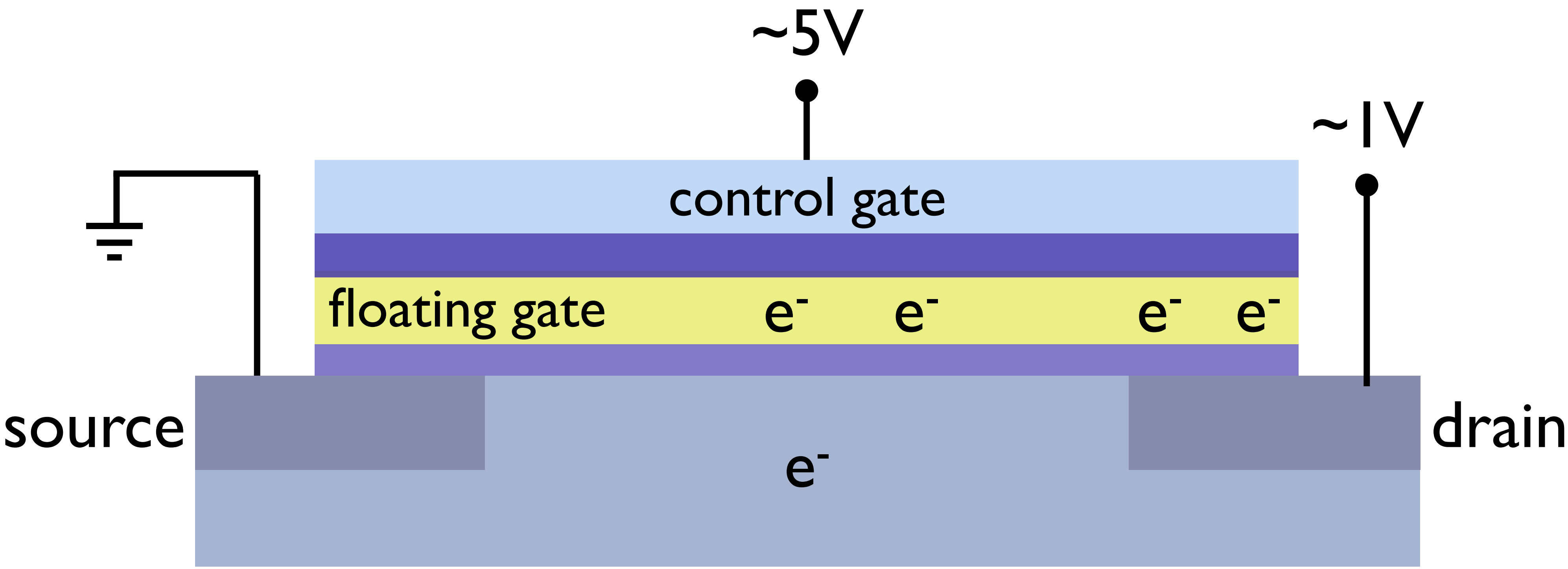

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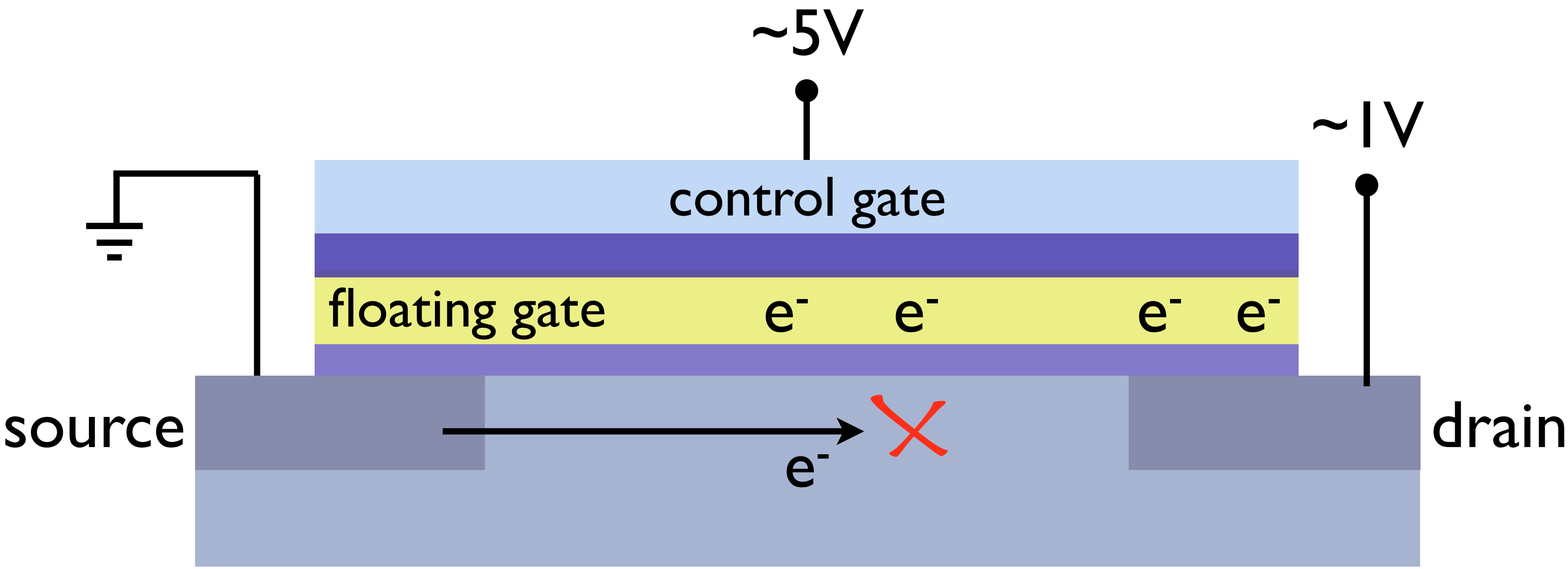

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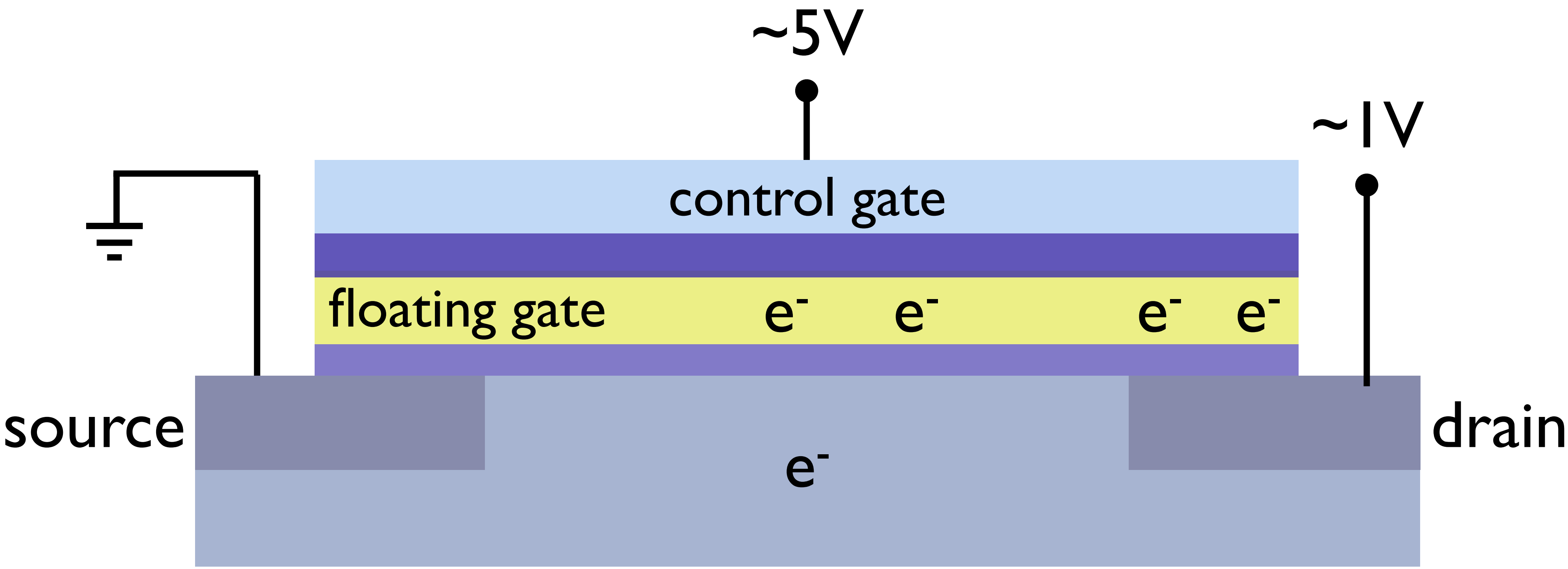

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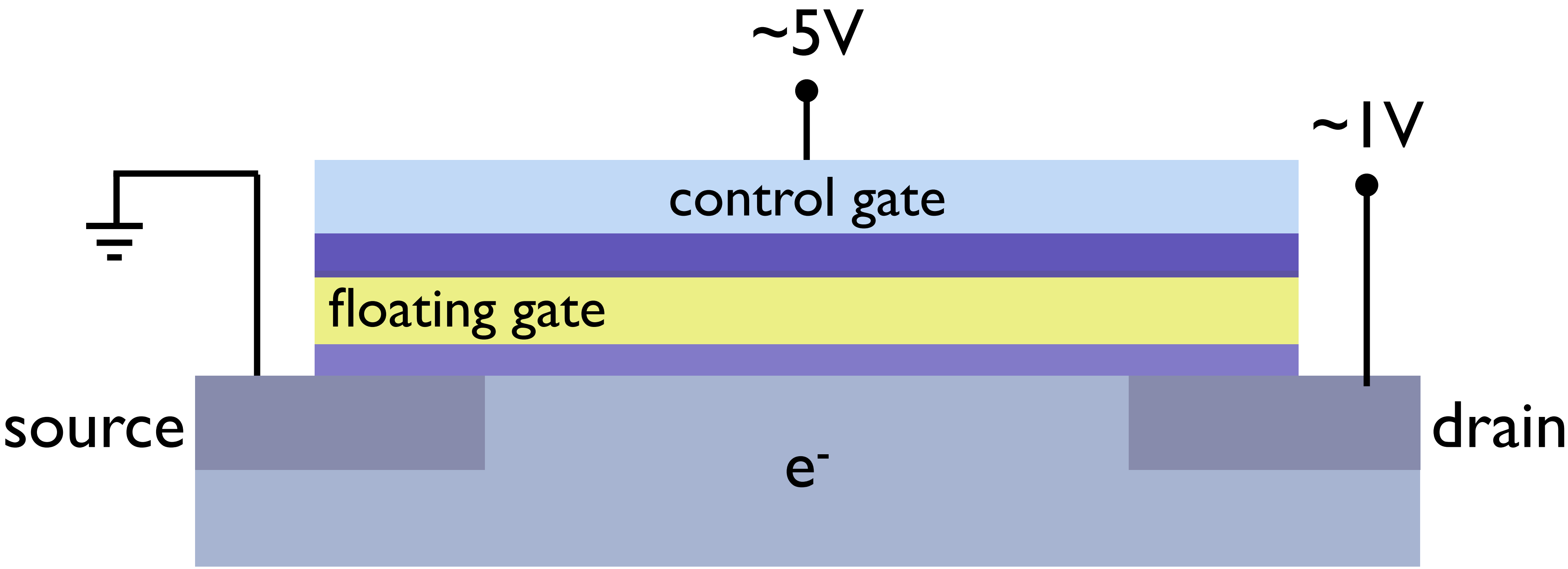

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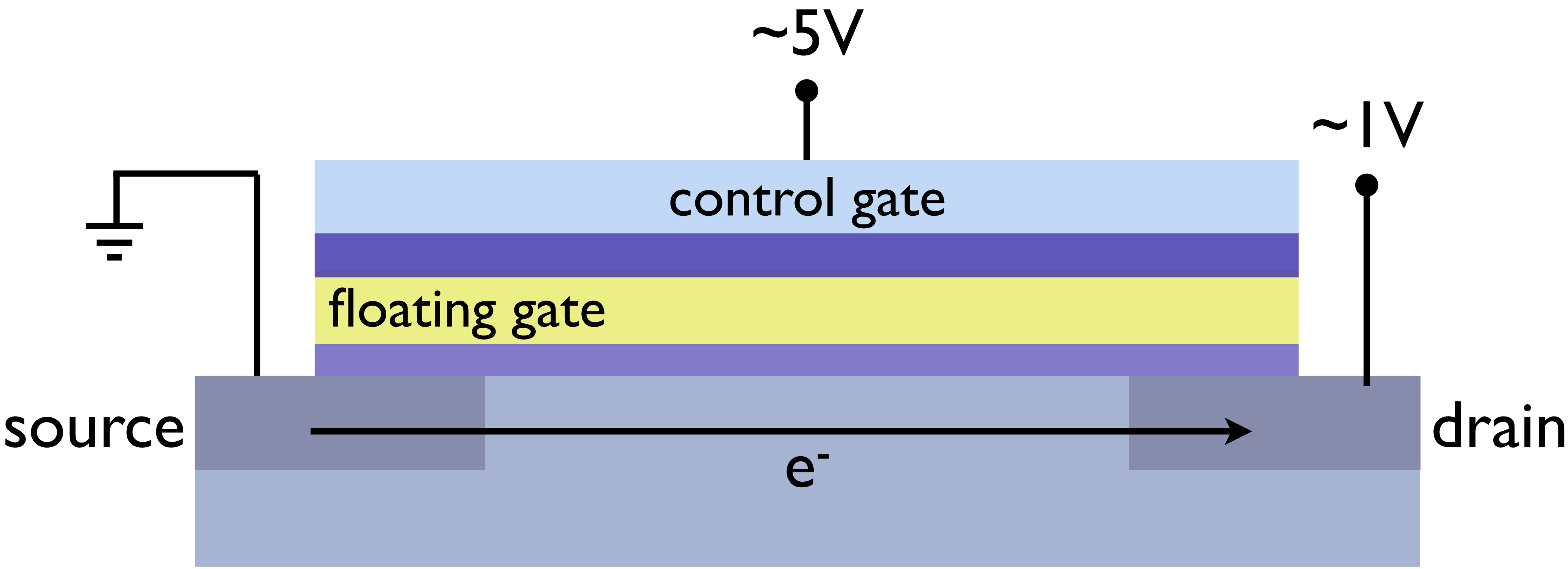

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the basics of Flash

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+ no mechanical limitations

+ lower latency

    = attractive for speed, noise, power consumption, reliability.

the basics of Flash

\+ no mechanical limitations

\+ lower latency

= attractive for speed, noise, power consumption, reliability.

− cost/GB still significantly higher (but decreasing rapidly!)

− finite number of erase/write (typically 10^6 cycles guaranteed)

unable to support an OS (swap!)

warranties on flash-based disks trending ≥ HDD

the basics of *phase change memory*

this is your homework ...

in 3 pages:

how does phase-change memory work?
advantages and disadvantages?
could it be disruptive?
who are the major players?

places to start:

G.A. Gibson et al, Appl. Phys. Lett. 86, 051902 (2005)

http://domino.research.ibm.com/comm/pr.nsf/pages/news.20061211_phasechange.html

Transcript

http://bama.ua.edu/~pleclair/PH587/

PDF version of these slides