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Non-volatile magnetic components for low-loss electronics and photonics

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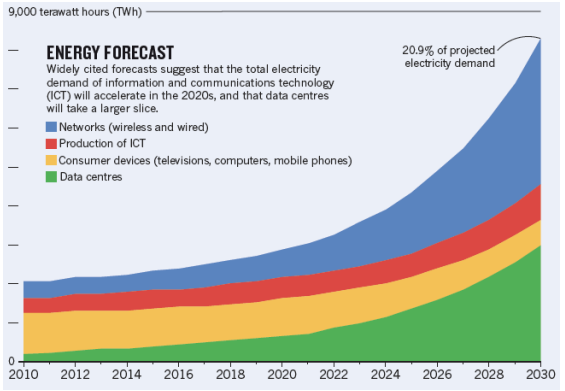
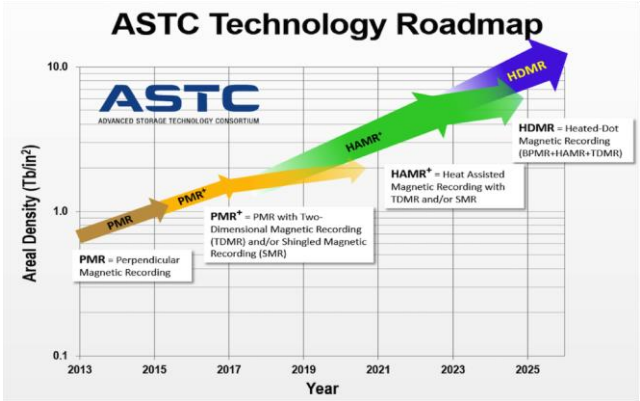
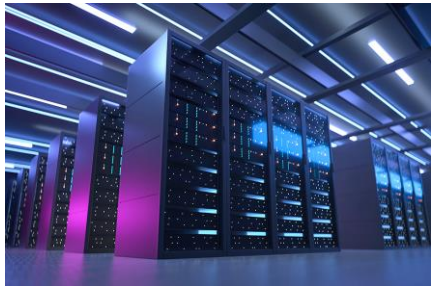
Big data: we have a problem

- Information and communication technology (ICT) will require between 8 and 20% of global electricity supply by 2030!
- Data storage demand grows at 40% per year.
- Much of our data is stored in server farms
- Hard disk drives provide the cheapest non-archival storage
- HDD capacity and storage follow a Moore's Law

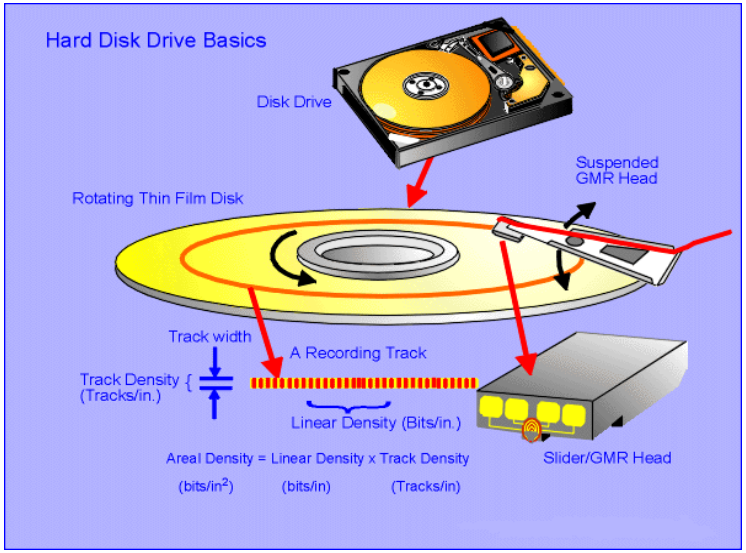


N. Jones Nature **561**, 163 (2018)

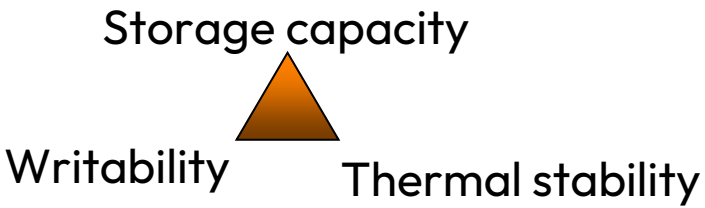




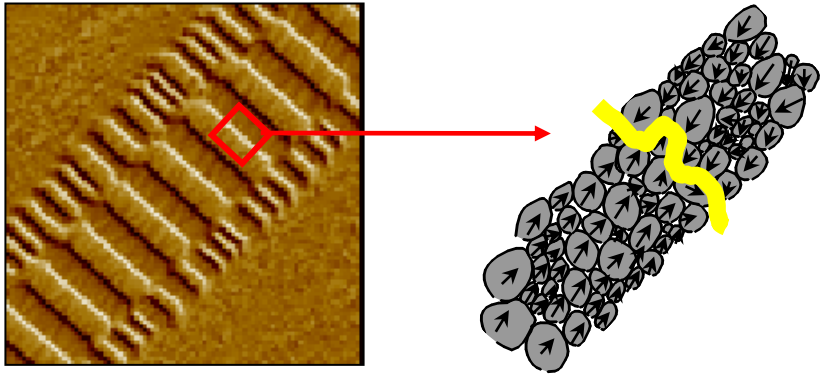
ICT: how it works



The magnetic recording trilemma:



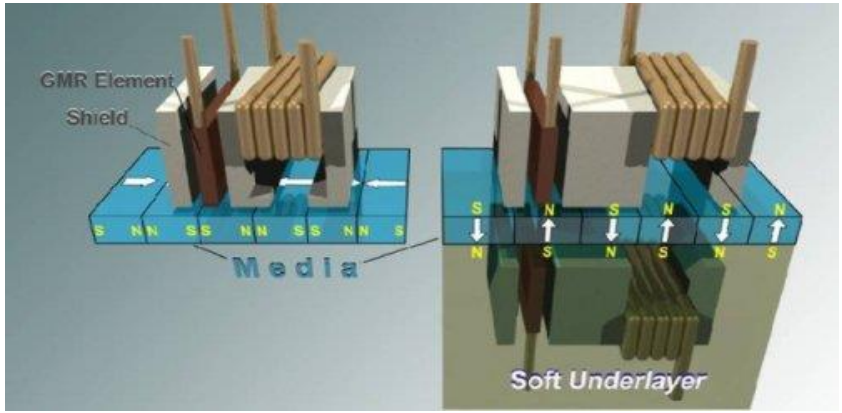
Let's look at a track more closely



- 1 'bit' consists of many grains
- Higher storage densities require smaller grains to minimize transition noise.
- BUT smaller grains are less thermally stable.

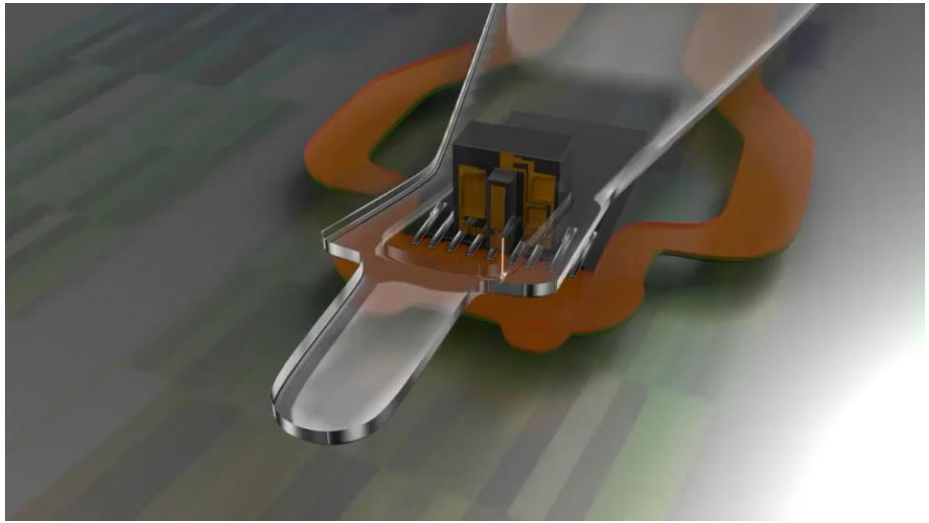
Scaling and paradigm shifts

Longitudinal to perpendicular recording



Perpendicular recording allows larger “write” magnetic fields to be used

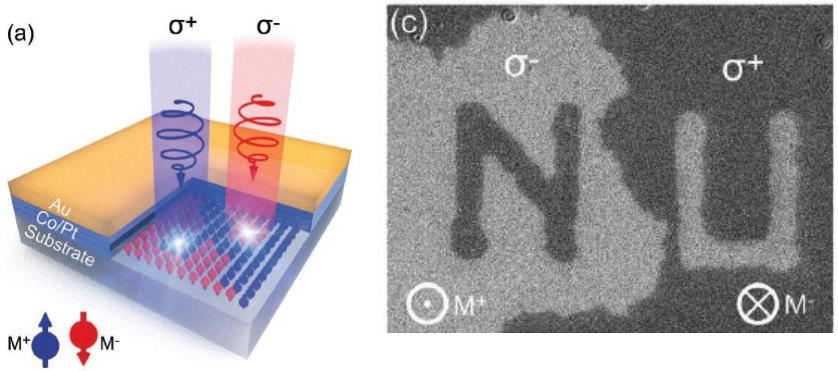
to heat assisted magnetic recording (HAMR)



BUT the quadrilemma means that the “write” field must increase again

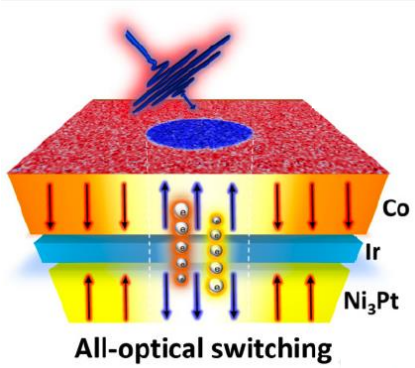
What the future might look like

What if the laser could generate an *effective* "write" field?



F. Cheng et al., Adv. Optical Mater. **8**, 2000379 (2020).
C.-H. Lambert et al. Science **345**, 1337 (2014).

We need to engineer the storage material and identify the most effective mechanism.



M. Dabrowski et al., Nano Lett. **21**, 9210 (2021)

For example, optically induced electron currents can transfer angular momentum.

What the future might look like

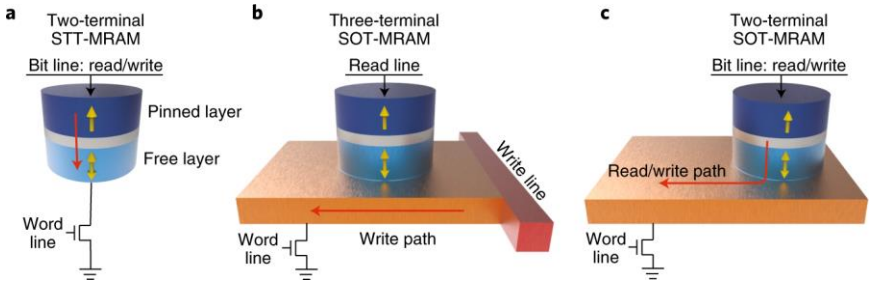
All optical switching (AOS) of magnetization must be fast (<10^{-10} s), and delivered on length scales <100 nm – not easy

But it opens many new possibilities:

- All-optical computing
- All-optical switching within telecommunications
- And the magnetic state is non-volatile, for low power operation
- Use of antiferromagnets could be even faster and doesn't require any additional energy or angular momentum

Not just optical

Non-volatility also offers significant advantages for electrical, microwave and THz devices

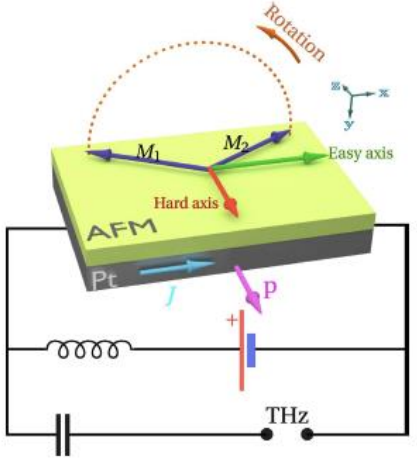


G. Yu Nature Electronics 1, 496 (2018)

MRAM:

- Fast, and high cycle endurance
- Already in production
- Further reduction of switching energy to enable use as cache

THz generation and detection in antiferromagnetic materials



R. Khymyn et al. Sci. Rep. 7:43705 (2017)

Closing remarks

- The rise of data is inexorable and threatens runaway energy consumption (and global warming)
- We need more capable hardware with greater capacity with lower energy consumption per operation
- Magnetic materials are inherently non-volatile for low energy loss
- All optical control of magnetism could provide new low-energy solutions throughout ICT.