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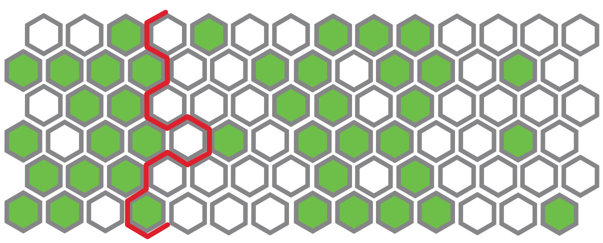
HAMR Technology

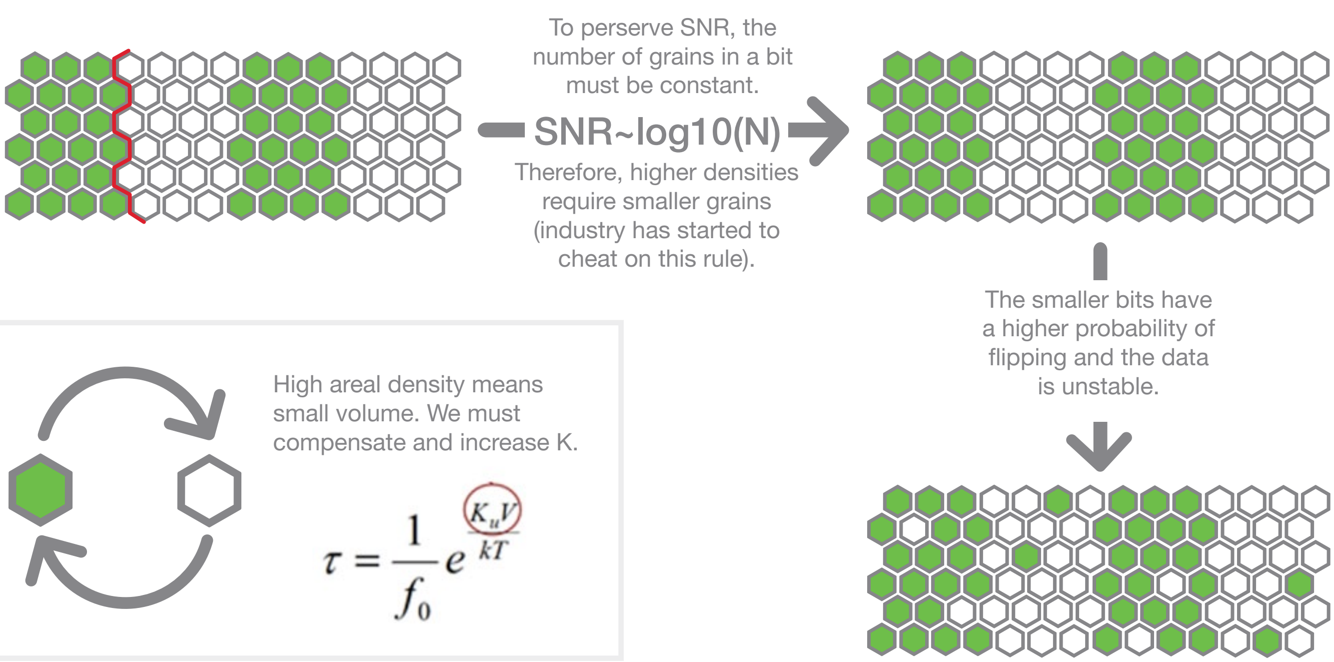
Increased Data Density

The capacity of hard drives needs to continue increasing to meet the demands of data growth. However, when bit density is increased thermal stability becomes a problem. In the following illustration, each colored region of grains represents a bit wherein each blue region (call it a “1”) and white region (call it a “0”) comprises several grains. As you can see, some of the grains have flipped to the wrong magnetic orientation within the encoded bit. This can lead to errors, so it must be avoided.

Thermal Stability



In order to increase areal density, we must shrink the volume of the grains on the media (represented by “V” in the formula below). When we do this, the grains become thermally unstable unless we also increase the anisotropy of the media (represented by “K”). Remember, anisotropy is the degree of difficulty required to change the magnetic orientation of grains on the media.



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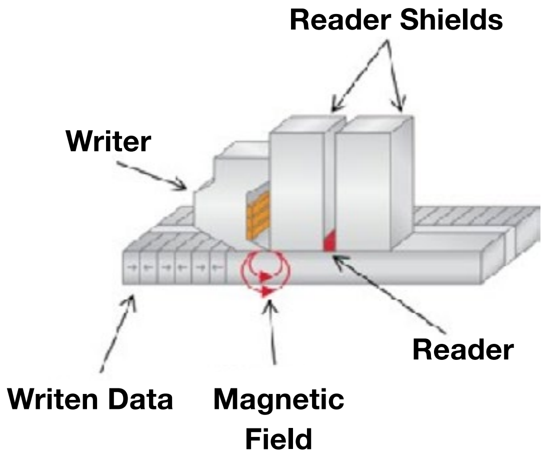
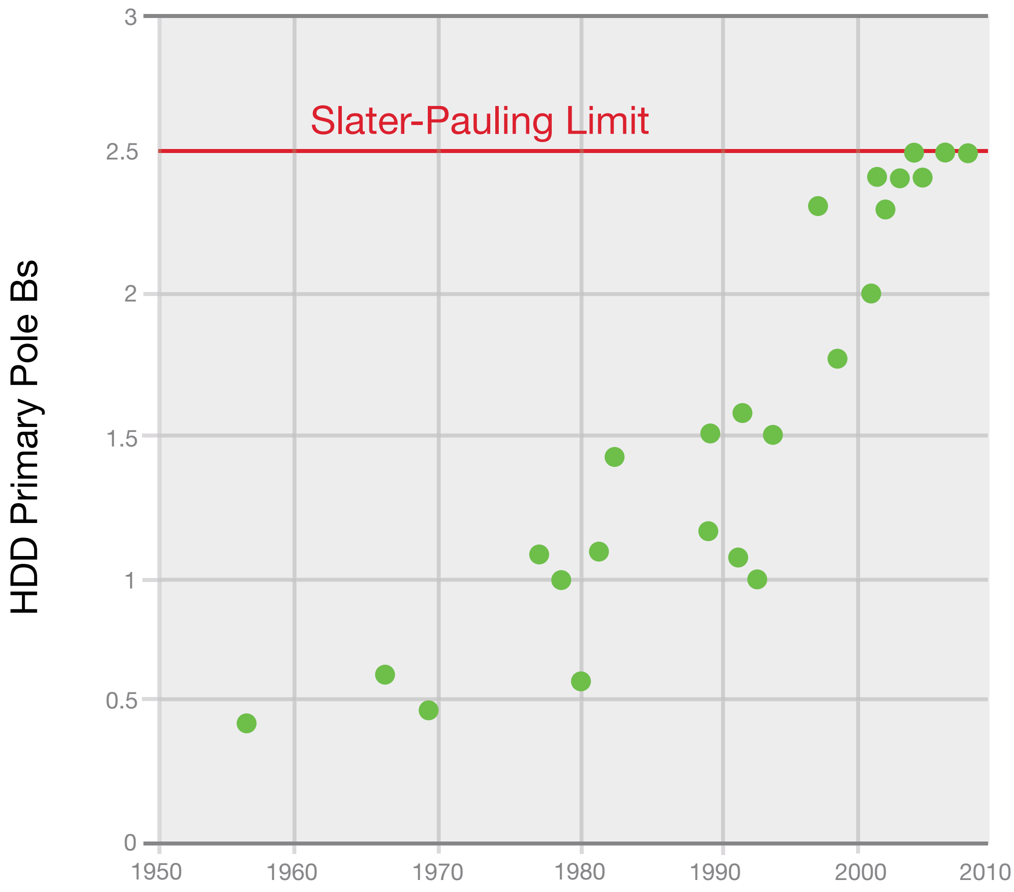
The Evolution of Data Density



The first hard drive used Longitudinal Recording (LR), which placed the magnetization in the plane of the disk. The field we write with is the fringing field, which is the field that leaks out from the deep gap of the field (see illustration right).

As we increased areal density and shrunk the size of the grains, we needed to increase the anisotropy of the media. However, when the media becomes more stable, writing becomes more difficult and more field is required to reliably change the direction of the grains on the media and record data. For 60 years, we have been increasing the field from the magnetic recording head, but ultimately hit a natural limit (see illustration below).



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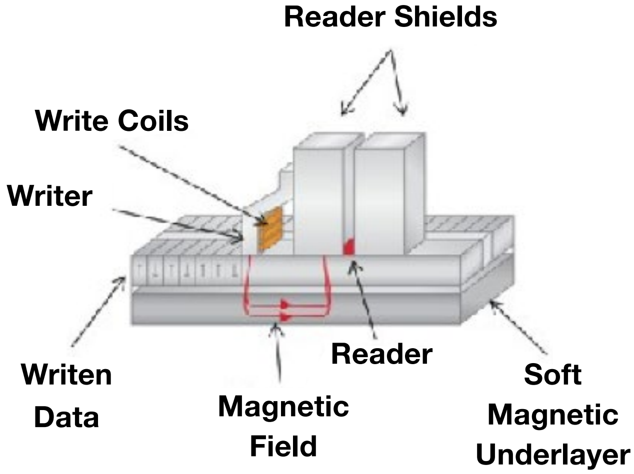
From PMR to SMR to HAMR

By using Perpendicular Magnetic Recording (PMR), we were able to add a soft underlayer on the media and effectively put the media in the “gap” of the writer where the field is larger, orienting each bit to sit perpendicular to the media instead of lying along its surface.

This allowed us to further shrink grain size and increase areal density.

The next evolutionary step was to develop Shingled Magnetic Recording (SMR). SMR achieves higher areal densities by squeezing tracks closer together rather than reducing bit size. Tracks overlap one another, like shingles on a roof, allowing more data to be written to the same space. As new data is written, the drive tracks are trimmed—or shingled.

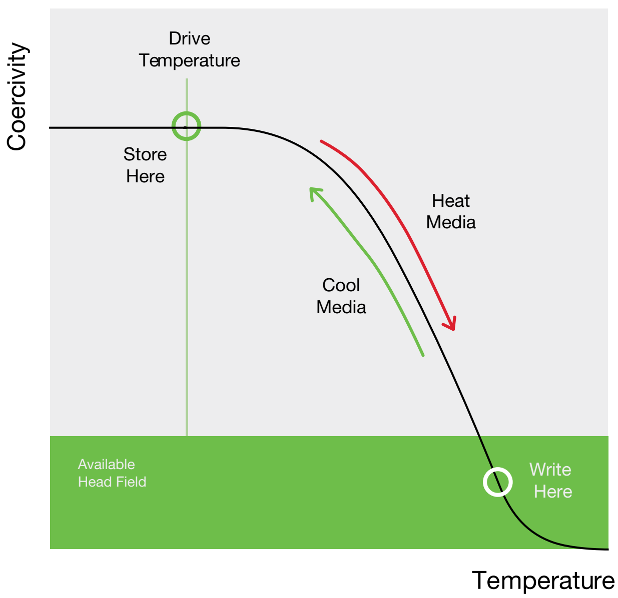


Because the reader element on the drive head is smaller than the writer, all data can still be read off the trimmed track without compromise to data integrity or reliability. In addition, traditional reader and writer elements can be used for SMR. SMR doesn’t require significant new production capital to be used in a product, which lets us deploy SMR-enabled hard drives while keeping costs low.

On its own, SMR offers a pretty significant boost in disk capacity. When we introduced the first SMR hard drive in 2014, we improved hard drive density by 25 percent. However, the underlying method by which the bits are recorded is the same. Thus, even with the combined benefits of PMR and SMR, we’re approaching the limits with this technology as well. Today’s PMR will eventually run out of steam just over 1 terabit per square inch (Tbpsi). Due to the laws of physics, we just can’t get enough field anymore.

High anisotropy iron-platinum (FePt) media allows us to overcome the thermal stability problems with traditional PMR media and high areal densities. With conventional recording heads, we can’t write to the media because we don’t have enough field.

Heat-Assisted Magnetic Recording (HAMR) allows us to get around this limitation by heating the media. At room temperature, the grains on the media are small and thermally stable. Just what we need. By heating the media, we can temporarily reduce the coercivity of the media.



We write the media when it is hot, and store it when it is cold (see illustration left). The entire process—heating, writing, and cooling—takes less than 1 nanosecond.

HAMR should take data density up to about 5tbpsi.

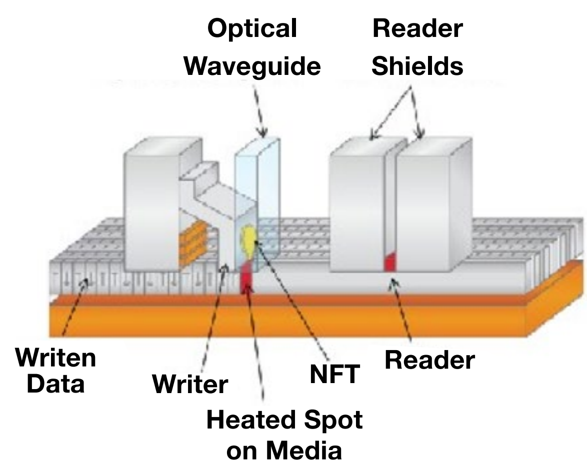
A HAMR head looks a lot like a PMR head. However, we add a laser, an optical waveguide, and a near-field transducer (NFT) to facilitate the heating of the media.

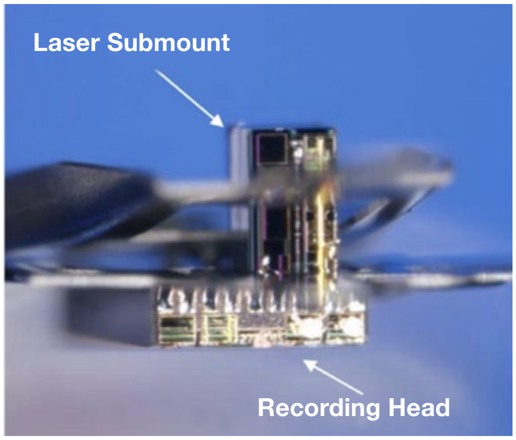
Designing a HAMR Drive

To build a HAMR drive, we had to:

- Add a laser diode to the head
- Develop an optical path to steer the light from the laser to the NFT
- Integrate NFTs into the recording head
- Develop new HAMR media
- Modify the firmware on the drive and in our test systems
- Adjust our manufacturing process to accommodate HAMR
- Do a million other little things that engineers spent countless hours developing

On a HAMR head, the laser is attached to the submount. An optical waveguide carries light from the laser to the NFT, which is integrated into the recording head (see image right).





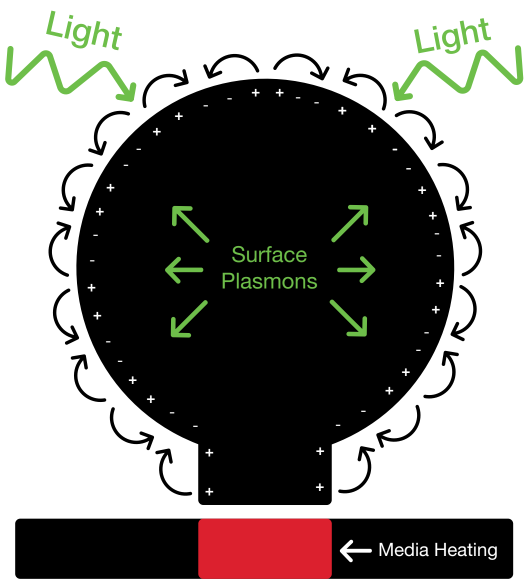
Beating Diffraction Limits

For over 100 years, we've known that diffraction limits the minimum optical spot size of focused propagating light waves in the far field. In a Blu-ray drive, a spot size of 238 nanometer (nm) is possible. By today's definition of track pitch in a hard drive, this is huge. Even if we played an optical trick and used near-field recording techniques, we still would not be able to focus light smaller than ~100nm. Clearly, another solution is necessary.

$$d_{FWHM} \cong \frac{0.5\lambda}{NA} = \frac{0.5\lambda}{\sin \vartheta}$$

To beat the diffraction limit we use surface plasmons to break the diffraction limit. This new component is called a plasmonic near-field transducer, or NFT for short. When light hits certain metals under special circumstances it gets turned into an electric surface current. This surface current and the associated electromagnetic fields are known as a surface plasmon. The surface plasmons propagate along the surface of the metal.

Surface plasmons are not new. We've been manipulating them for thousands of years. Consider the stained glass windows used in European cathedrals as early as the 7th century. The artists mixed metals with glass to create color. When light of a certain color hits the metal particles in the glass they are absorbed and turned into heat or scattered in all directions. The light that is not absorbed passes through the glass and into your eye, creating the perception of color.

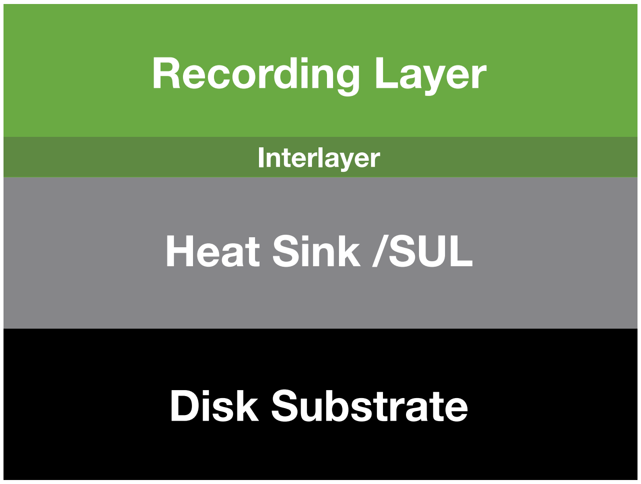


The Seagate plasmonic NFT works on the same principle. Our plasmonic NFT consists of a disk and a peg. Light is absorbed by the disk and turned into a surface plasmon. This surface plasmon travels along the outside edge of the disk and down the peg, heating that precise point on the media. The width of the peg is the width of the hot spot on the media. This is much smaller than the diffraction limit—and that's how we beat the diffraction limit.

Over the last 15 years, we've matured the design significantly from this basic concept and first test designs. At this point, we've made more than 25 million plasmonic NFTs during the life of the HAMR development program.

HAMR media advances

Of course, the design of the recording media had to be completely reengineered for HAMR. The substrate is made of a special HAMR glass material that allows us to deposit the recording layer at a high temperature. For HAMR, we needed to add a heat sink and interlayer to control the heat flow from the storage layer. Too fast would necessitate lots of power. Too slow would cause the thermal energy to spread and erase adjacent data. Finding the right balance is critical to HAMR's success. The overcoat had to be changed to survive being heated to more than 400°C and still maintain a reliable interface between the media and the recording head.



Bringing HAMR to customers: leadership in advanced research is crucial

We believe this technology is nearly ready for commercialization. Seagate is committed to making this technology work, and we have the best engineers in the world working toward volume shipments of 20+ terabyte (TB) drives in 2019.

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Seagate joined 12 other founding members to announce the formation of the Advanced Storage Technology Consortium (ASTC) on November 9, 2010. Each year since, Seagate and member companies contribute money to ASTC to fund university research in pre-competitive storage technologies.

In addition, every year ASTC publishes a technology roadmap to help prioritize our university funding and align our suppliers and customers to our industry consensus roadmap. The current roadmap can be found at the IDEMA website by following the links to ASTC.

Where does the technology roadmap lead?

As the roadmap shows, we'll continue to extend PMR for another few years with the introduction of helium-filled drives, SMR, and multiple readers.

Public HAMR demonstrations have already achieved 2.0Tbpsi. HAMR drives with application-ready, power-on, and reliability specifications are already in the hands of customers for test purposes—and are performing to expectations with no special code or system modifications on their part, and no wear leveling tricks in the drive on ours.

In 2017, Seagate announced plans to make the first hard drives using Heat-Assisted Magnetic Recording, or HAMR, available by the end of 2018 in pilot volumes. HAMR is on track to deliver 20TB+ drives in volume by 2019, and to continue thereafter with a forecasted 30 percent CAGR (compound annual growth rate) in data density to achieve 40TB or higher by 2023.

Eventually we will also combine HAMR with bit patterned media. We call this Heated Dot Magnetic Recording (HDMR), and the industry consensus is that 100TB drives will be possible with this technology in the future.

There will be more after HDMR, and we're looking at all kinds of new and exciting storage technologies to continue to meet the needs of the world's insatiable demand for low-cost, high-capacity reliable storage.

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AMERICAS Seagate Technology LLC 10200 South De Anza Boulevard, Cupertino, California 95014, United States, 408-658-1000
ASIA/PACIFIC Seagate Singapore International Headquarters Pte. Ltd. 7000 Ang Mo Kio Avenue 5, Singapore 569877, 65-6485-3888
EUROPE, MIDDLE EAST AND AFRICA Seagate Technology SAS 16–18, rue du Dôme, 92100 Boulogne-Billancourt, France, 33 1-4186 10 00