

PGM HIGHLIGHTS

Platinum in Next-Generation Materials for Data Storage

Introduction

Magnetic memory in the form of hard disks has been in use in the computer industry since the first hard disk system was commercially released by IBM in 1956. That first system stored 2000 bits of data per square inch, equivalent to about 5 MB in total on 50 separate 24-inch diameter disks (1, 2), but data storage capacity grew exponentially throughout the latter half of the twentieth century, in tandem with – and sometimes outstripping – growth in processing power (3, 4).

The capacity of a hard disk system depends on many factors, but is fundamentally dictated by how much information the magnetic medium can hold (3, 5). This can be quantified using areal density: the number of bits per unit of surface area, currently quoted in gigabits per square inch (Gb in^{-2}). For magnetic memory to keep pace with developments in the computer industry and see off challenges from competing solid-state memory technologies, areal densities must continue to grow rapidly. The next frontier in storage capacity will see density values of commercial systems of the order of terabits per square inch (Tb in^{-2}). However, significant technological innovation will be necessary to bring this about (3, 4).

Much of this innovation will centre on the magnetic medium: how it is structured and what materials are used. Existing media contain platinum (Figure 1) and, more recently, ruthenium (6, 7). These metals offer a number of advantages in the magnetic storage of data and they have played an integral part in delivering the growth in areal density seen to date (2, 8–10). Demand for both in this application is significant, amounting to over 95,000 oz of platinum and over 50,000 oz of ruthenium in 2009 (6). It is therefore worth considering what role the platinum group metals (pgms) will play in increasing storage capacity into the future.

In fact, the pgms feature prominently in new materials currently under research (3). This article has selected one example of a platinum-based material as illustration of this, with two contrasting approaches

highlighted. This is intended to give a flavour for the challenges facing the pursuit of higher areal densities and the novel ways in which these may be overcome.

The Limitations to Areal Density

Magnetic recording exploits the phenomenon of ferromagnetism. Ferromagnetic materials align with an applied magnetic field and retain much of this alignment as remnant magnetism after the external field has been removed; in other words they exhibit bulk anisotropy. In a granular ferromagnetic medium, data can therefore be encoded in the spatial orientation of the remnant magnetic fields of successive groups of grains, with each group then constituting one bit. The information is held in the transition from one bit to the next; the head will return a '1' or '0' depending on whether or not it picks up a change in direction (3).

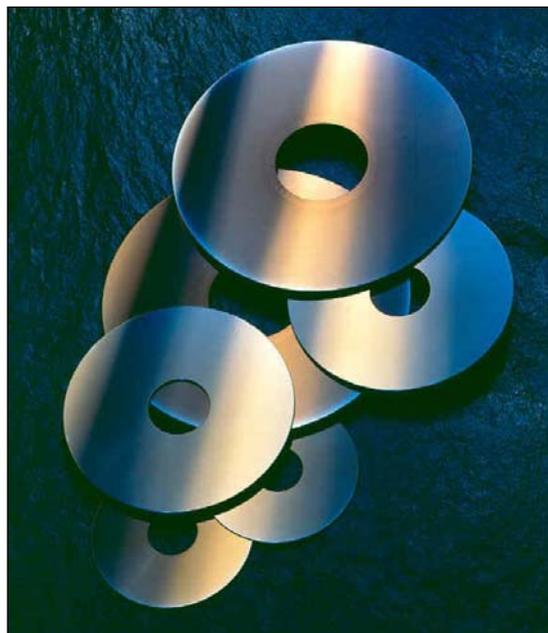


Fig. 1. Platinum alloy coated hard disks (Courtesy of Platinum Today)

Clearly, density is increased by reducing bit size and allowing more bits to be packed in per square inch. Bit size can be reduced in two ways: by including fewer grains per bit and by making the grains themselves smaller. This is by no means straightforward and in practice has to be weighed against other performance parameters. The persistence and integrity of the data recorded in the magnetic medium is of particular importance: the bit configuration should be stable, ideally for five years or more, and the signal output from the bits should degrade only minimally (2). These factors place stringent requirements on the medium that limit the extent to which bits can be downsized (4, 11).

The first requirement is an acceptable signal-to-noise ratio (SNR). In conventional granular media, grains are irregular in shape, size and arrangement. In addition, the magnetic fields of grains in adjacent bits may become coupled so that they do not align independently. These imperfections give rise to noise in the data and therefore each bit must consist of a number of grains sufficient for the average to be used as a distinguishable signal (2, 3, 11).

The second requirement is that the medium be thermally stable. For a given material, the smaller the grains are, the lower their energy barrier to magnetisation reversal – making it more likely that the data will be disrupted by thermal variations in the environment. Each ferromagnetic material is therefore subject to a lower limit for grain size below which data cannot be stably encoded: the superparamagnetic limit (11).

The recent introduction of perpendicular magnetic recording (PMR) facilitated improvements in both SNR and data stability by changing the orientation of the bits in the plane of the medium and adding a soft underlayer to enhance the write field (3, 11–13) (Figure 2). As a result PMR has allowed continued growth in data storage capacity, beyond what was thought achievable with conventional thin-film media. However, existing PMR media are not a complete departure from these conventional media and are still subject to the above-mentioned constraints limiting eventual reduction of bit size. Therefore, although the limit to areal density has been greatly deferred, it still exists. It is generally considered that to achieve densities much beyond 1 Tb in⁻² new materials will be necessary (3, 4).

Shrinking Bits

In the light of this, there are various approaches to be taken in developing media with reduced bit size.

In the first instance, fewer grains would be necessary per bit if the medium were more regular with distinct transitions between bits. In the ideal case, bit shape and size would be consistent and the bits would be arranged in uniform arrays. There are a number of strategies currently being explored to improve regularity in magnetic media, with the concept of patterned media receiving particular attention (2–4), notably from Hitachi Global Storage Technologies, Ltd (Figure 3) (13).

Bits can also be made smaller if the superparamagnetic limit to grain size is lowered. The energy

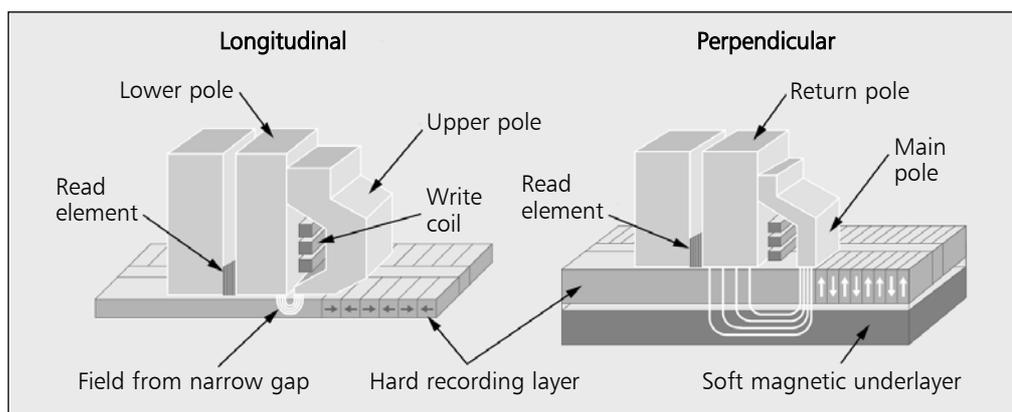


Fig. 2. Comparison of conventional (longitudinal) and perpendicular magnetic recording (PMR) modes. PMR enables higher density by orientating the bits perpendicular to the disk, reducing repelling forces between bits and allowing higher head fields (13). The recording layer in each typically contains platinum. Reprinted from (13) with permission from the authors and Hitachi, Ltd

barrier of a grain in the absence of an external field, E_B^0 , is given by $K_u V$, where V is the volume of the grain and K_u is the magnetic anisotropy constant (giving the magnetic anisotropy energy per unit volume) (3). Hence, to maintain the energy barrier while decreasing grain size, material with a higher anisotropy constant must be used. The medium then possesses a higher coercivity, H_c , a measure of the intensity of the magnetic field which must be applied to remove all the remnant magnetism of the material and a good indicator of data stability. This also means that a more intense field is required to write, and overwrite, the data. As materials with very high anisotropy energy come into use, this may prove problematic due to practical restrictions on the magnetic field of the head. The problem is not insurmountable and is the focus of much research and development, particularly into methods of microwave-assisted magnetic recording (MAMR) or heat-assisted magnetic recording (HAMR), in which the head carries an energy source to locally heat each bit as it is written, temporarily lowering the coercivity. After writing, the bit is then quenched and returns to high coercivity so that the information is stabilised (2, 4, 14).

Iron-Platinum Nanoparticles

Novel materials with large values of K_u and which can be used in a highly regular form are thus being sought.

Iron-platinum alloys of approximately equimolar composition are known to have high K_u values, specifically in the ordered tetragonal $L1_0$ phase (3). Furthermore, it is possible to form $L1_0$ FePt nanoparticles of very small size (around 3 nm) with a high degree of chemical stability (15, 16).

The use of nanoparticles in recording media has been proposed as an extension of the concept of patterned media. Patterned media consist of arrays of magnetic islands arranged in a nonmagnetic matrix. The grains within one bit (or island) are exchange coupled and act in concert, while being completely decoupled and independent from surrounding bits. Bit transitions are thus sharp, and the averaging required in conventional granular media is not necessary. However, ultrahigh densities (10 Tbit in⁻² or more) will most likely not be achieved using current nanofabrication techniques such as lithography as it becomes increasingly difficult to manufacture structures on the very small scales required (2, 3). Nanoparticles, while potentially offering the same advantages as bit-patterned media, are generated by chemical synthesis and form arrays through self-assembly, allowing smaller sizes to be obtained and facilitating regular arrangement on a substrate. Equally importantly, nanoparticles tend to be monodisperse. Variation in size can be limited to below 5% (15), compared with 20–30% in granular media (17).

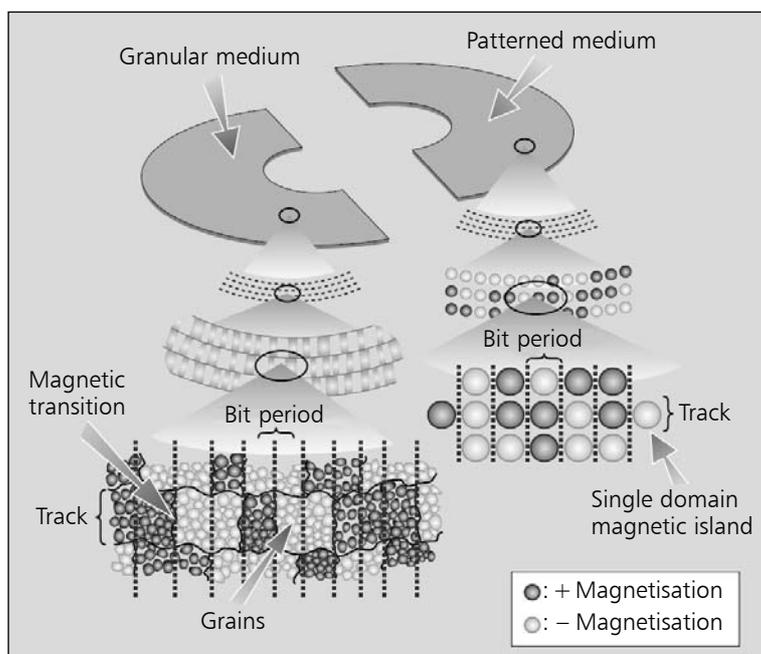


Fig. 3. Patterned media replace the many random grains of conventional, continuous thin-film media with one large magnetic island that stores a single bit. The bits can then be scaled to smaller size, allowing higher density while remaining thermally stable. Reprinted from (13) with permission from the authors and Hitachi, Ltd

FePt nanoparticles would therefore fulfil both the requirement for high anisotropy energy and the need for uniformity. However, there are a number of problems with the use of FePt nanoparticles which must be overcome to make them viable for magnetic recording.

Nanocubes

A patent from Seagate Technology LLC in the USA, one of the leaders in this field, reports progress on this front (18). It addresses two concerns: firstly, the fact that it is difficult to align the magnetic axes of spherical FePt nanoparticles once deposited on a surface and, secondly, that they produce a relatively small magnetic signal. The inventors claim a method for producing nearly cubic or rectangular FePt nanoparticles, 4–10 nm in size, which have their facets parallel to the (001) crystallographic plane (Figure 4)(19). During deposition onto a substrate, cubes will assume greater regularity than spheres simply because to be stable the cubes must have one facet flat on the plane and therefore parallel to it. The cubic nanoparticles are found to arrange themselves with their [100] axes perpendicular to the surface, and their [010] and [001] axes parallel to it and aligned locally with each other in square arrays. In addition, these cubic nanoparticles produce a larger signal than spherical particles of similar dimensions. This is because signal strength depends on the magnetic thickness of the medium, and magnetic thickness of nanoparticles has been shown to be a function of their geometry: square is better (18).

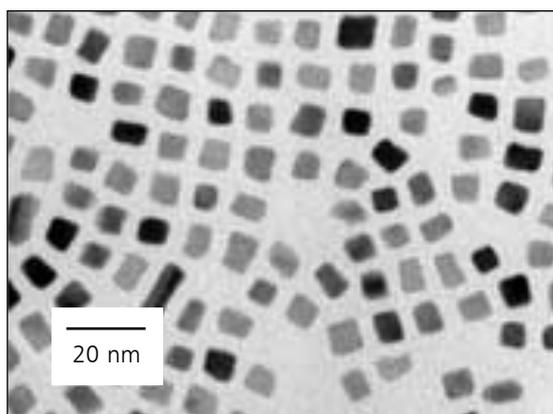


Fig. 4. Bright-field transmission electron microscope (TEM) micrograph of unannealed iron-platinum nanocubes, deposited from a non-polar solvent on a carbon-coated copper TEM grid. Reprinted from (19) with permission from Elsevier

There is, however, a potentially more serious limitation which this patent claims to have made only partial progress towards solving. Typically, FePt nanoparticles are produced *via* synthesis methods that form a magnetically soft face-centred cubic (fcc) crystal structure. Annealing is then necessary to transform the structure to the magnetically hard face-centred tetragonal (fct) phase (2, 16). The drawback with heat treatment after synthesis is that it may lead to undesirable particle aggregation and magnetic coupling – precisely what patterned media are designed to prevent. The higher-temperature synthesis technique proposed in this patent does appear to induce some phase transformation from fcc to fct during formation of the particles, but it is likely that further annealing will be necessary.

The inventors do not address in this patent the issue of how to write data in a medium which is so magnetically hard that the required switching field is beyond the intensities achievable with existing head technology. However, it can be assumed that this patent forms part of a strategy that Seagate has previously publicised: the use of HAMR in combination with FePt nanoparticles (20).

Capped Nanoparticles

A European research group may have found a way to harness the advantages of both FePt alloy and nanoparticles, without the attendant disadvantages described above. The proof of concept was carried out in the MAFIN project (for ‘magnetic films on nanospheres: innovative concept for storage media’), which was funded under the EU’s Sixth Framework Programme (21, 22). Instead of nanoparticles composed of ferromagnetic material, the group used silica nanospheres with a thin layer of the magnetic medium deposited as a cap. Initially, researchers looked into using multilayers of cobalt/platinum or cobalt/palladium as the magnetic medium (17, 23, 24) but in this project the focus moved to FePt as a promising material (21).

If the deposition is done correctly, the spherical shape of the silica particles causes the magnetic film to form uniform, decoupled islands. Deposition of the film can be controlled to impart perpendicular anisotropy to the islands, or a ‘tilted’ medium can be created (Figure 5 (a)). Coercivity depends on the angle between the switching field and the magnetic easy axis of the particle. By tilting the medium, materials with a high K_u can be made more easily writable (17, 24).

As the nanoparticles are not themselves magnetic, they can be arranged adjacent to and in contact with each other in closely packed arrays (Figure 5 (b)). The nanospheres are ~25 nm in diameter and if they are packed tightly, a storage density of 1 Tb in⁻² should be possible. A successor project (TERAMAGSTOR for 'terabit magnetic storage technologies') is aiming to produce smaller spheres and higher densities (25). The research group has also proposed a novel way to write and read the FePt bits, using a fine probe with a magnetic tip (21).

Concluding Remarks

Ten years into the 21st century, data storage is still dominated by magnetic memory, particularly in the form of hard disk drives (HDDs) (26). While portable devices, and even some desk-top PCs, are now using solid-state drives (SSDs), their cost-per-GB of capacity remains at least an order of magnitude higher than that of HDDs (27, 28). This is likely to be the case for some years yet. Of more immediate concern, perhaps, are the demands placed on the technology by the need for ever-increasing storage capacities. While the

limits of existing materials are approaching, many new materials now in development are poised to deliver step-changes in areal density growth.

The pgms have featured in many major developments in magnetic data storage, of which perpendicular magnetic recording is the most recent example, and they look set to continue doing so. Just two examples of applied research into pgm-based materials have been discussed here, but there are many more. It is quite possible that the platinum group metals may once again prove to be key in realising the standard medium for HDDs of the future.

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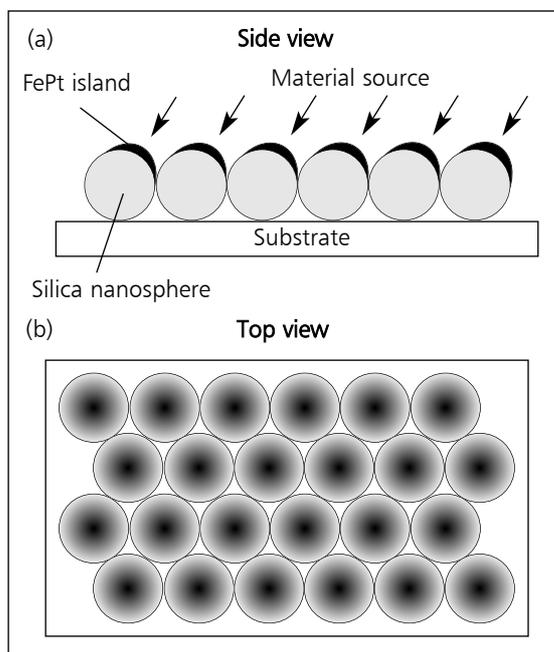


Fig. 5. (a) Silica nanospheres with isolated magnetic caps of iron-platinum alloy, in this instance deposited at an angle to create a medium with a tilted anisotropy axis; (b) As the silica nanospheres are not themselves magnetic they can be tightly packed to maximise density (17)

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