Platinum/Cobalt Multilayers

THE NEXT GENERATION MAGNETO-OPTIC DATA STORAGE MEDIUM

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At the heart of personal computers in current use is the hard magnetic disk drive, which provides the software programmes and data with long term storage. The increasing use of Windows, the graphically based computer interface which enables users to run several programmes simultaneously, has meant that an ever-increasing amount of data storage space is required. With Windows itself requiring some 15 megabytes (Mb) of storage space and individual Windows programmes typically taking up 10 to 15 Mb each; the average Windows personal computer (PC) now needs at least 100 Mb of storage space to contain a useful number of programmes and data. The trend for more long term storage will inevitably accelerate with the growth in multimedia applications, which combine photographs, video clips and sound into PC applications. With a single high quality photograph requiring up to 30 Mb of storage space, future PCs are expected to need hundreds, and possibly thousands of megabytes of storage space on the desktop.

At present the mainstream of magnetic hard disk drives can provide up to about 1000 Mb locally. Optical data storage, on the other hand, provides an accessible route to larger data storage densities since the use of a non-contacting laser to access the data allows for data bit sizes of around 1 micron from the focused beam and enables disks to be easily removed so that several disks can be used with a single drive. Three

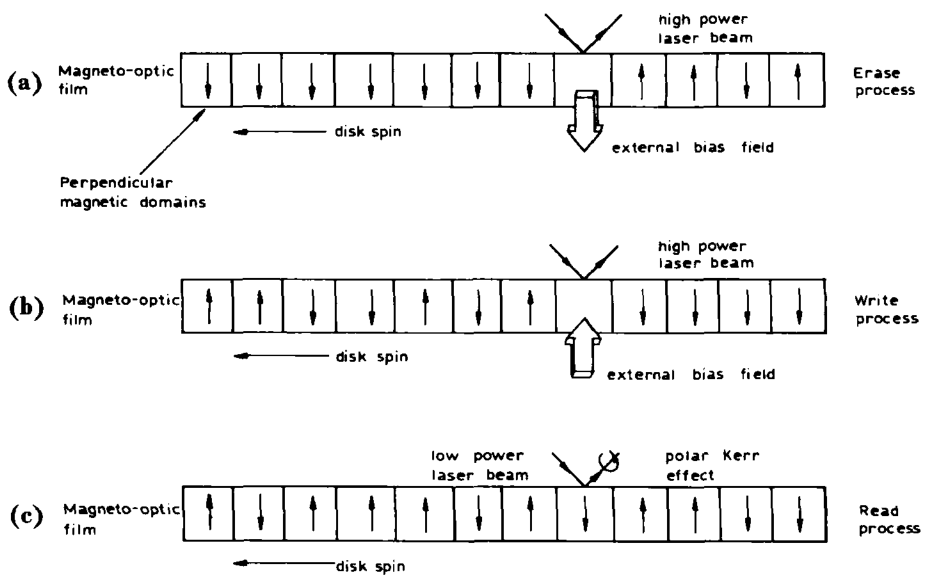

Fig. 1 The erase, write and read processes occurring in magneto-optic film on exposure to a laser beam and a magnetic field. The read process employs a lower powered laser beam than the erase and write processes

Fig.2 Research and development into disks and drives of the next generation is well advanced, as evidenced by this Johnson Matthey platinum/cobalt magneto-optic disk

types of optical data storage media are in common use, CD-ROMs (Compact Disk Read Only Memory) being the most widespread at present. These disks are prepared using the same technology as audio compact discs and enable data to be read from but not written to the disk. CD-ROM disks can hold 650 Mb on a single 5.25 inch diameter disk. Their main uses are in database or software distribution. WORM (Write Once Read Many times) technology has become established as a niche market for archival data storage. The advantage of WORM disks is that once thay have been written to, they cannot be changed and so provide a permanent record.

Several optical data storage methods have been developed where the data can be written and subsequently erased. These include Phase Change Erasable and dye polymer systems, but the one which has become the most widely established to date is magneto-optic data storage. Magneto-optic disks of diameter 5.25 inches currently available provide a removable, overwritable medium with 650 Mb of storage. During 1993, new agreed standards are likely to result in the commercial availability of 1200 Mb 5.25 inch disks and 256 Mb 3.5 inch disks. The technology for these disks still uses a magnetic thin film on which to store the data, but instead of a magnetic read/write head, a finely focused laser beam is used to write, read and erase the magnetic domains, as is shown in Figure 1.

The three main elements of the magneto-optic storage system are: the magnetic film, which has a high perpendicular magnetic anisotropy, that is the domains are oriented perpendicularly to the plane of the film; the laser beam, which can be used at high or low power; and the bias coil which can provide an external biasing magnetic field in either the "up" or "down" directions. Figure 1a shows the erase process. Here the external magnetic field is pointing downwards and the laser beam, at high power, heats up each domain in turn to above its Curie temperature, while the magneto-optic disk spins round its vertical axis. The Curie temperature of a magnetic material is the temperature above which it loses its coercive magnetic field and is typically around 200°C in these rare earth films. As the domains cool, they take on the orientation of the external bias field, and all the domains point downwards. This is equivalent to all the binary information bits being set to "zero". The write process is now shown in Figure 1b. Here the external bias field is reversed and the high power laser beam heats selective domains to above their Curie temperature, which as they cool take on a reversed magnetic orientation, thus setting these information bits to "one". At room temperature the magneto-optic films have high coercivities, typically of several thousand oersteds, which make the domains very stable and much less susceptible to magnetic change than conventional magnetic storage media. The high laser power reduces this coercivity to a figure approaching zero near its Curie temperature, thus allowing the domain to be reversed by the relatively low strength external magnetic field. Finally, Figure 1c shows the read process. Here a low power laser beam is used so that the magnetic properties of the film remain unchanged. The different magnetic orientations are read by means of the polar Kerr effect, in which the plane of polarisation of the reflected laser beam is rotated to the left or to the right, depending on the magnetic pole from which it is reflected. A detector system is used to record the polarisation shift and thus the magnetic orientation of the domain.

Magneto-optic disks and drives have only been available in quantity in the marketplace since 1991, but already research and development into disks and drives of the next generation is well advanced, see Figure 2. The technology of the current generation reads, writes and erases using infrared semiconductor lasers which form domains of about 1.0 micron in diameter. The use of shorter wavelength blue lasers will enable much smaller bits to be written and permit a fourfold increase in data storage density to be achieved. The development of blue lasers small enough to be incorporated into disk drives is likely to be achieved within the next few years by doubling the frequency of current generation semiconductor lasers, although a significant worldwide research effort on new materials systems for blue semiconductor lasers is also underway.

The magnetic films used in present day magneto-optic disks are based around amorphous rare earth-transition metal alloys, typically TbFeCo or GdTbCo, which have a good perpendicular magnetic anisotropy, high coercivities and relatively large polar Kerr rotations, θ_k.

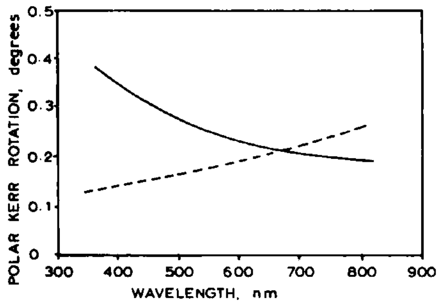

Fig.3 The polar Kerr rotation as a function of the wavelength for rare earth-transition metal alloy, ----- GdTbFe, and for platinum/cobalt multilayers —— of configuration n × (4 Å Co + 9 Å Pt)

However, as can be seen from Figure 3, the key magneto-optic property, the polar Kerr rotation, diminishes rapidly for such materials as the wavelength of the light is reduced from infrared to blue (1). Of the new materials systems that have been considered as future replacements for the rare earth-transition metals, the most promising is that of platinum/cobalt multilayer thin films. Figure 3 shows that this material possesses an increasing polar Kerr rotation as the wavelength of the incident laser beam is reduced and should give a superior performance to rare earth films at short wavelengths. These multilayers are prepared by alternately sputtering ultra-thin films of platinum and cobalt to give a structure of the type shown in Figure 4, where each metal layer is just a few ångströms thick.

The use of platinum/cobalt multilayers can provide other benefits as well. Although extremely thin, they are remarkably stable on exposure to air, unlike the equivalent rare earth-transition metal films and should provide for an inherently stable disk structure. This may enable simpler disk structures to be used.

Developments in Platinum/Cobalt Technology

Platinum/cobalt multilayers were first investigated, together with palladium/cobalt multilayers, during the mid-1980s, initially as a material for magnetic recording, when it was discovered that these multilayers had a high perpendicular magnetic anisotropy (2). In 1989 research groups from both Sony and Du Pont reported the development of platinum/cobalt multilayer films with good perpendicular magnetic anisotropy and polar Kerr rotation, even though the film coercivity was still low at around 500 Oe (3, 4).

Further work from Du Pont and Philips Research resulted in the preparation of high coercivity multilayers of over 3kOe, prepared by sputtering using krypton or xenon, rather than the usual argon, and by using a zinc oxide underlayer (5).

At Johnson Matthey, research into platinum-containing magneto-optic media has been underway since 1988. This research programme has included collaborative work with Coventry University on both multilayer modelling (6) and on platinum manganese antimonide magneto-optic films (7).Our in-house programme has focused on investigating the production of high quality magneto-optic platinum/cobalt multilayers using argon sputtering, which should provide a simpler route to commercial production than krypton or xenon sputtering. We have found that close control over the argon sputtering process has enabled us to control the film coercivity over a wide range of values (8).

Typical polar Kerr hysteresis loops for identical platinum/cobalt multilayers prepared here at the Technology Centre are shown in Figures 5. In each case a square loop is observed, which demonstrates excellent perpendicular magnetic anisotropy while a high polar Kerr rotation has been maintained. The out-of-plane coercivity defined as the point where the loop crosses the

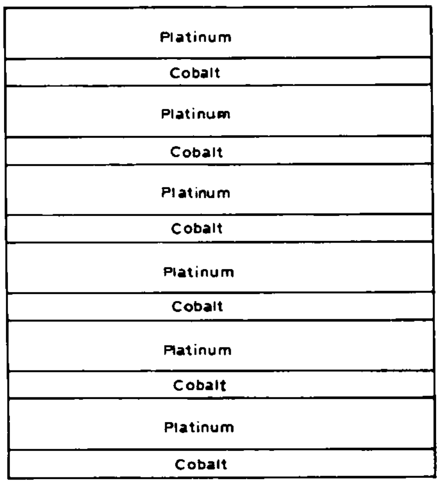

Fig.4 Typical construction of platinum/cobalt multilayer film

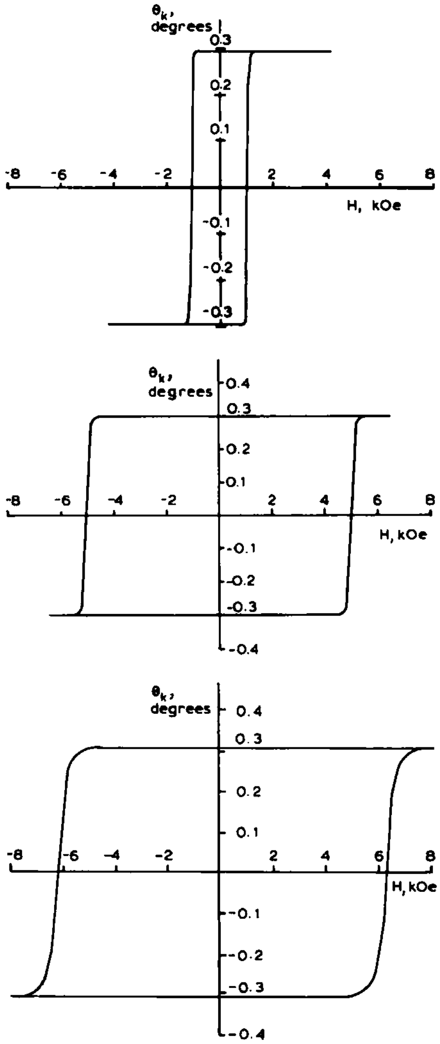

Fig. 5 Hysteresis loops showing the response of the magneto-optic polar Kerr rotation of identical 8Å platinum/3Å cobalt multilayers to changes in applied magnetic field. The x-axis crossover indicates the film coercivity, H_c

x-axis, is seen to be controllable from levels of 1 kOe or below, up to over 6 kOe. While the ideal coercivity for a magneto-optic disk will also depend on the optimisation of other disk properties, this degree of control provides the means to make large changes in these other properties without restricting the film coercivity to unacceptably low levels.

The other basic multilayer property that needs to be controlled is that of the Curie temperature. Typical platinum/cobalt multilayers tend to have Curie temperatures at least one hundred degrees higher than rare earth films, and a higher laser power is therefore required to write to or erase the film. These Curie temperatures may need to be reduced in future platinum/cobalt magneto-optic systems as blue lasers may not have the relatively high powers of present day infrared lasers.

Several workers have now shown that increasing the platinum layer thickness in the multilayer can reduce the Curie temperature. For instance, at Johnson Matthey we have produced multilayers with differences of over 120°C in their Curie temperatures, by increasing the platinum thickness from 8 Å to 15 Å, as shown in the Table below.

Films with very high platinum/cobalt ratios tend to have reduced polar Kerr rotations, and therefore such an approach, on its own, is not ideal. We have also shown that the Curie temperature varies with the number of platinum/cobalt periods (9). Figure 6 shows the effect of the number of platinum/cobalt periods on the Curie temperature for otherwise identical multilayers of configuration platinum 8 Å/cobalt 3 Å.

Several research groups have investigated the effect on Curie temperature of additives to the platinum/cobalt multilayer. Philips Research have recently reported that the addition of a few per cent of elements, such as rhenium, osmium, rhodium, iridium and ruthenium, to the cobalt layer can be useful in lowering the Curie temperature, with rhenium and osmium in particular maintaining anisotropy and the hysteresis loop shape (10). Sony Research have used nickel as an additive to the cobalt layer which has produced similar results (11).

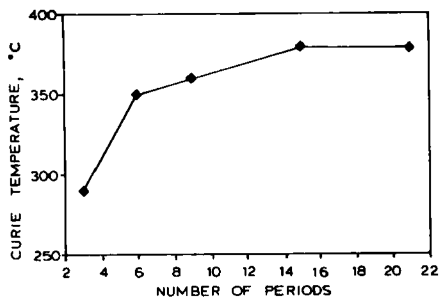

Fig.6 The variation of the Curie temperature with the number of platinum/cobalt periods for Pt 8 Å/Co 3 Å multilayers which are otherwise identical

Platinum/Cobalt Disk Production

Magneto-optic disks containing platinum/cobalt are currently being prepared and tested in many laboratories worldwide, including those of Johnson Matthey, and their superior performance at short wavelengths, compared to that of rare earth-based disks, is now well established. There are, however, several key technical issues that need to be addressed in order to commercialise this new technology. These include long term stability of the multilayer structure

Variation of Curie Temperature with Platinum Thickness in a Platinum/Cobalt Multilayer

Cobalt thickness, Å	Platinum thickness, Å	Number of Pt/Co periods	Curie temperature, °C
3	8	9	365
3	15	9	240

and also the noise levels that can be achieved.

The stability of the interfaces of a platinum/cobalt multilayer to repeated laser pulses is an issue that has been investigated by Sony Research, where the noise level of a series of platinum/cobalt disks has been measured as a function of both disk structure and Curie temperature (12).

It was found that those disks with a structure or a low Curie temperature that enabled a lower peak temperature for writing to be used were the ones which maintained good noise figures over long write/erase cycles. Platinum/cobalt disks which were exposed to consistently higher writing temperatures experienced a long-term degradation in noise levels which was ascribed to atomic mixing at the platinum/cobalt interface.

Noise levels in platinum/cobalt disks have been shown by Sony Research to be related to the smoothness of the silicon nitride underlayer and the degree of the (111) crystal orientation in the platinum/cobalt multilayer (11). The higher polar Kerr rotation of platinum/cobalt at shorter wavelengths should lead to improved noise figures compared to rare earth disks as the wavelength is reduced, and several groups have now reported this.

Sony have prepared, by using xenon sputtering, platinum/cobalt disks with higher carrier to noise levels of 6 to 8 decibels (dB) than rare earth disks, at 488 nm read/write wavelengths (11). Philips Research investigated magneto-optical performance over a range of wavelengths and found that their platinum/cobalt disks gave a higher (2–3 dB) noise level than a rare earth disk at wavelengths of 820 and 647 nm (13). However, at 458 nm the result was reversed with the platinum/cobalt disk performing 3 dB better than the rare earth disk.

Conclusions

Platinum/cobalt multilayers are fundamentally an attractive option as magneto-optic data storage media for the next generation because of their inherent nobility and their excellent magnetic and optical properties at short wavelengths. Significant advances have been made in optimising the magnetic properties of these multilayers by using standard argon sputtering processes, which makes the commercial production of disks based on this technology feasible. Noise levels for platinum/cobalt magneto-optic disks have the potential to equal those of rare earth-transition metal disks at currently used laser wavelengths and to become superior as the read/write wavelength shortens.

While much detailed work is still required to turn this technology into a commercial product, the future of platinum/cobalt magneto-optic disks shows great promise.

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