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Effects of magnetic states in recording media on moisture adsorption and surface hydrophobicity

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Abstract

In magnetic data recording, humidity is the most dangerous environmental factor that affects the stability of storage media carriers. It will lead to the magnetic media deterioration and also adversely affect the tribological performance at the head–disk interface. At every data bit of recording, the transition area in a longitudinal recording media has a near-perpendicular magnetic direction, either at north or south magnetic polarity. This investigation showed that a perpendicularly magnetized floppy disk at the south polarity was able to retain and adsorb water molecules into its coating media. The north polarity was found to have shown the exact opposite effect. As a result of this phenomenon, the physical surface condition and the surface hydrophobicity of a magnetized floppy disk has been affected. The interaction with moisture from the south-polarized disk could become ideal sites for fungus growth, which eventually affects the carrier's stability and its tribological performance.

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Keywords: Surface magnetism; Magnetic media; Atomic force microscope; Contact angle; surface hydrophobicity

1. Introduction

Magnetic media has been used for recording and data storage for a long time since the early 1930s [1,2]. In present permanent data storage peripherals, such as hard disk, its longitudinal magnetic media is housed in air-tight enclosure to prevent dust and moisture from getting in. However, in the temporary data storage peripherals, such as floppy disk (FD) and magnetic tape, the longitudinal magnetic media is open to the environment, which will be exposed to environmental dust and moisture. In magnetic data recording, humidity is the most dangerous environmental factor that affects the stability of the media carrier [3].

It is known that the presence of moisture on the recording media can be devastating. Water is the agent of chemical deterioration process of polymers by hydrolysis [4]. Moreover, high humidity encourages fungus and mould growth, which will limit its shelf life. Environmental humidity also plays a significant role in the tribology performance of the head–disk interface (HDI). It is known that friction and stiction increases with an

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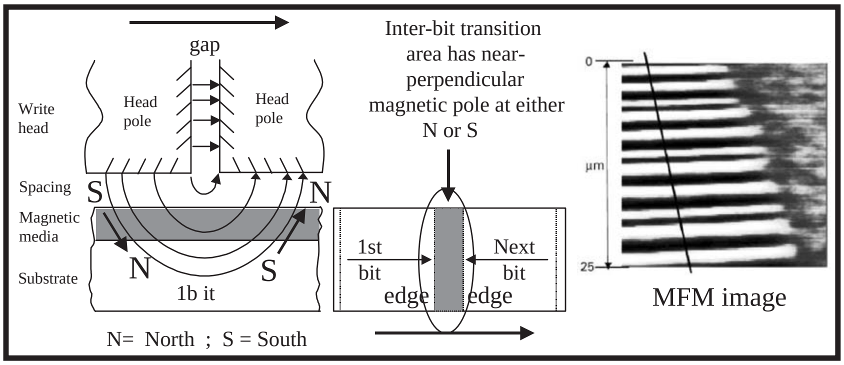

Fig. 1. The transition area between a bit which gives rise to a perpendicular magnetic polarity [2]—inserted MFM image is adopted from Ref. [7].

increase in humidity [5]. However, the mechanism of water molecules adhering to the magnetic media has always been assumed to adhere by wetting process [6]. There are limited studies on the magnetic effects in the recording data at the transition or the edges of every data bit, which has the physical characteristics of either a near-perpendicular north magnetic pole or a south magnetic pole as shown in Fig. 1 [7].

At these magnetic surfaces, the magnetic atoms have fewer neighbors than the interior ones. These surface magnetic atoms have a lower coordination than that of the bulk and as a result, a reduced symmetry is occurred [8,9]. Based on research studies on ferromagnets, the surface magnetic moments from these un-paired electron spins at the free surfaces are in fact enhanced by the narrowing of the electronic 3d-bands [9,10]. The electronic bands for the surface electrons in the spin-up state is filled and has a higher density of d states (or surface energy), as compared to the spin down state, which contains holes and at a lower density of states [11–14].

Hence, depending on the spin direction, the combined effects of enhanced magnetic moments from unpaired electron spins at the surface and the increased in the anisotropy exchange forces would expect to cause the magnetic surface to be in two different energy states; one higher in the spin up and the other lower in the spin down. Based on Gibbs theory [15], the surface excess free energy would affect the equilibrium thermodynamic force balance, which can be quantified by the surface tension. This change in the thermodynamic force equilibrium would affect the total surface free energy on the magnetic surface.

Moreover, water, being dipolar, can be partly aligned or dielectrically polarized by the electric field [16]. And some research work has found that low magnetic fields (0.2 T) have been shown, in simulations, to increase the number of monomer water molecules [17] and they also increase the tetrahedrality at the same time, which could assist the clathrate formation [18]. As a result, an electrostatically negative charged surface would increase the evaporation rate of water and the dissolution rate of oxygen. This would cause the surface to become relatively more hydrophobic in nature.

In this report, an experimental investigation is conducted to study the effects of perpendicularly polarized (with respect to the surface) magnetic media, which exist at every transition area after a recording process. Specifically, the impact of environmental moisture on the media and its effects on hydrophobicity are characterized.

2. Material and methods

To evaluate the magnetic effects with environmental moisture, the experiments were conducted by magnetically polarizing the magnetic media globally, thus giving rise to only one perpendicular ordered magnetic state. Commercially available $3\frac{1}{2}''$ FDs were used as magnetic samples.

On the qualitative analyses, the atomic force microscope (AFM) [19], and the scanning electron microscope (SEM) were used for imaging. Lorentz microscopy [3] was conducted in the SEM for confirming the magnetic states in the polarized substrates. The choice for selecting the AFM was its ability to conduct imaging on the sample in their natural environment at high resolution [20]. The contact angle-measuring instrument [21,22] was also used. The evaluation was made with the presence of any moisture that may be absorbed into the magnetic media, which in turn will affect the surface hydrophobicity.

2.1. Sample preparation

The $3\frac{1}{2}''$ FD (formatted and unwritten) was dismantled and the ferrimagnetic film coating, consisting of organic binders, resins, and the magnetic coated media of cobalt modified ferric oxide (Co-γ-Fe_2O_3) on the flexible polyethylene terephthalate (PET) substrate [2,3], was extracted from the diskette assembly. With only the double-sided coatings on the PET substrate, the sheet was cut into smaller strips of approximate $10 \times 20\,mm^2$ size. Thereafter, each strip was globally magnetized perpendicularly to the sample surface by placing it directly onto a Neodymium-Iron-Boron (NdFeB) permanent magnet block (L50 $\times$ B50 $\times$ H30 mm) with an external magnetizing field of up to 5000 Oe. One strip (which is non-polarized) was used as a reference and the other two pieces are polarized under the north and south magnetic field separately. Exposure time was set at 60 h. After magnetization, the substrates were kept at inverted position (using clips) to prevent dust settling and exposed to the environment at room conditions of room temperature between 21°C and 23°C and relative humidity between 70% and 75%. This was to allow interaction between the substrates with the environmental moisture. Exposure period was set at 72 h, which was adequate for moisture absorption to reach an equilibrium state [23].

2.2. SEM and Lorentz microscopy

The scanning electron microscope (SEM Leica S360) equipment was used for imaging the magnetic polarized substrates. The imaging was done with the probe and filament current at 1.5 and 2.67 A, respectively. The acceleration voltage used is 20 kV. For the Lorentz microscopy (SEM Leica S360), the experiment was carried out at the low magnification of about 6 times. The SEM setting for the Lorentz microscopy was the same as that for SEM imaging.

2.3. Atomic force microscopy

A commercial AFM (Nanoscope IIIa, Digital Instruments Inc., Santa Barbara, CA) equipped with a J-type scanner was employed. 120 μm-long V-shaped cantilever with spring constant of 0.58 N/m and oxide sharpened Si_3N_4 tip (Veeco Instruments) was used. Images with scan areas of 10×10 and $1 \times 1\,\mu m^2$ using 512×512 pixels were acquired under the condition of contact mode in air.

Imaging in liquid was also performed using a standard fluid cell without the o-ring seal. Images with a scan area of $10 \times 10\,\mu m^2$, 256×256 pixels were acquired for tapping mode in liquid, at a drive frequency of approximately 8.0–8.4 kHz and scanning rate of 1 Hz. More than 10 samples were collected for every magnetized-condition substrates.

2.4. Contact angle measurement

The contact angles determined at room temperature (22°C) by the sessile drop method with a contact angle measuring instrument (First Ten Angstroms, FTÅ200) and a polar liquid (distilled water). Sessile drops of an average 3.4 μl were deposited with a 10 ml syringe and a 0.1 mm ID gauge 34 needle (MicroFil MF34G). The syringe pump rate was set at 0.2 μl/s. Contact angles were measured on different magnetically polarized and non-polarized substrates and at opposite sides of each drop. At least 20 measurements were taken for each conditioned substrate.

3. Results

3.1. SEM imaging and Lorentz microscopy

The north, south and non-polarized neutral substrates were imaged in SEM at a magnification of 10,000 times (equivalent to the AFM $10 \times 10\,\mu m^2$ scanned area). Lorentz microscopy was also conducted at the same time in the SEM to verify the magnetic state of the substrates. Typical images of SEM are shown in Fig. 2, which suggested no physical or topographical differences between all three magnetic states. Enlargement of images to 20,000 times produced the same results.

The Lorentz microscopy results in Fig. 3 showed that the magnetic states in the north and south-polarized substrates were present. The image for the north-polarized substrate is darker in contrast as compared to that of the south polarized substrate.

3.2. Atomic force microscopy

The north and south polarized and the neutral non-polarized magnetic media were first imaged at a $10 \times 10\,\mu m^2$ (see Fig. 4) under contact mode in ambient air. The image is equivalent to $\times 10{,}000$ in the SEM magnification. The 3D image of the south-polarized substrate (Fig. 4(a)) was observed to have numerous swollen lumps of about $0.5\,\mu m$ or less over the entire surface (highlighted in circles). Whereas in the north polarized substrate (Fig. 4(b)), there was no such observed phenomenon. For the neutral non-polarized substrate (Fig. 4(c)), the 3D topographic image appeared in-between the north and the south-polarized substrates. Generally, the lumps appeared fewer than the south substrates (highlighted in circles).

A closer view as shown in Fig. 5 was carried out at $1 \times 1\,\mu m^2$ (equivalent to a $\times 100{,}000$ SEM magnification) under the contact mode in ambient air. Prior to the 72 h-humidity exposure test, the three different states of the magnetic substrates were found to be similar in structure (see Fig. 5(a) for south polarized, Fig. 5(b) for north polarized and Fig. 5(c) for non-polarized). The substrates appeared generally flat with the step height averaged about 11.5 nm. The average surface roughness (R_a) measured was 5.4 nm. However, after the 72 h-humidity exposure, the south-polar-

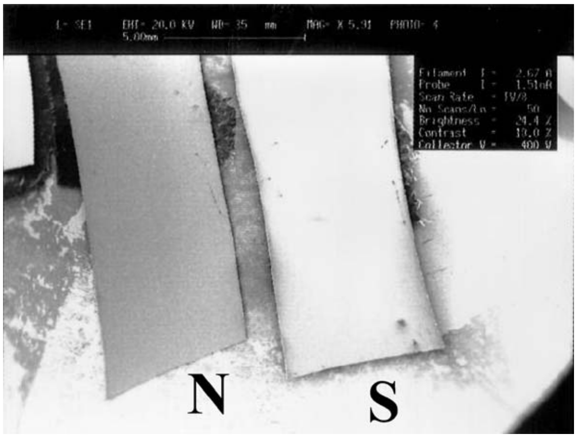

Fig. 3. Lorentz microscopy image at $\times 6$ times on the magnetic north (left) and south (right) polarized substrates.

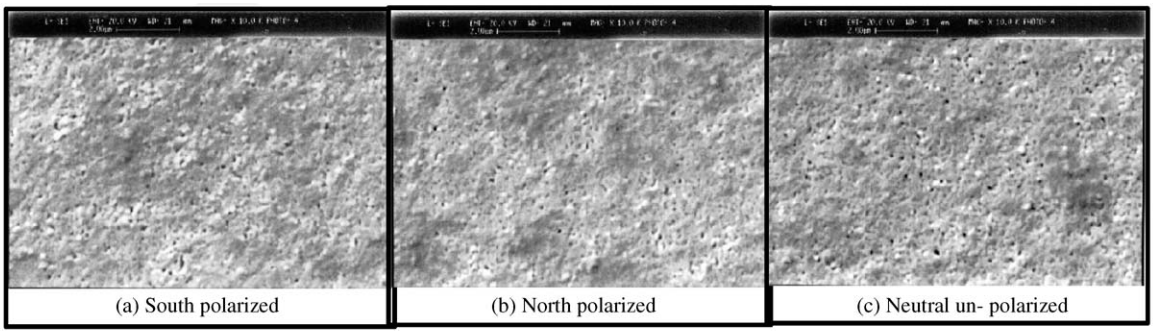

Fig. 2. SEM imaging at $\times 10{,}000$ times on different magnetized conditions substrates.

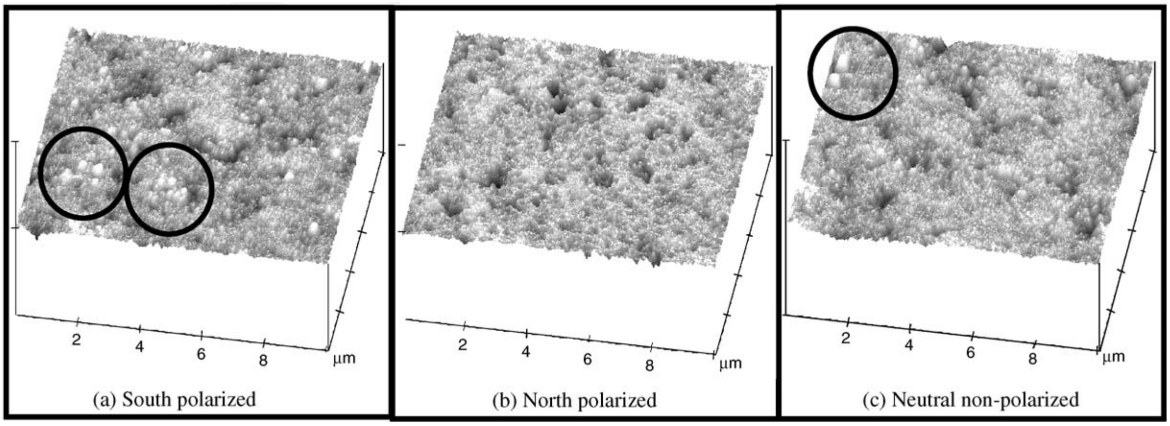

Fig. 4. Contact mode AFM in ambient air @ $10 \times 10\,\mu m$ resolution on different magnetized condition substrates (images rotated 10° and pitch angle 35°).

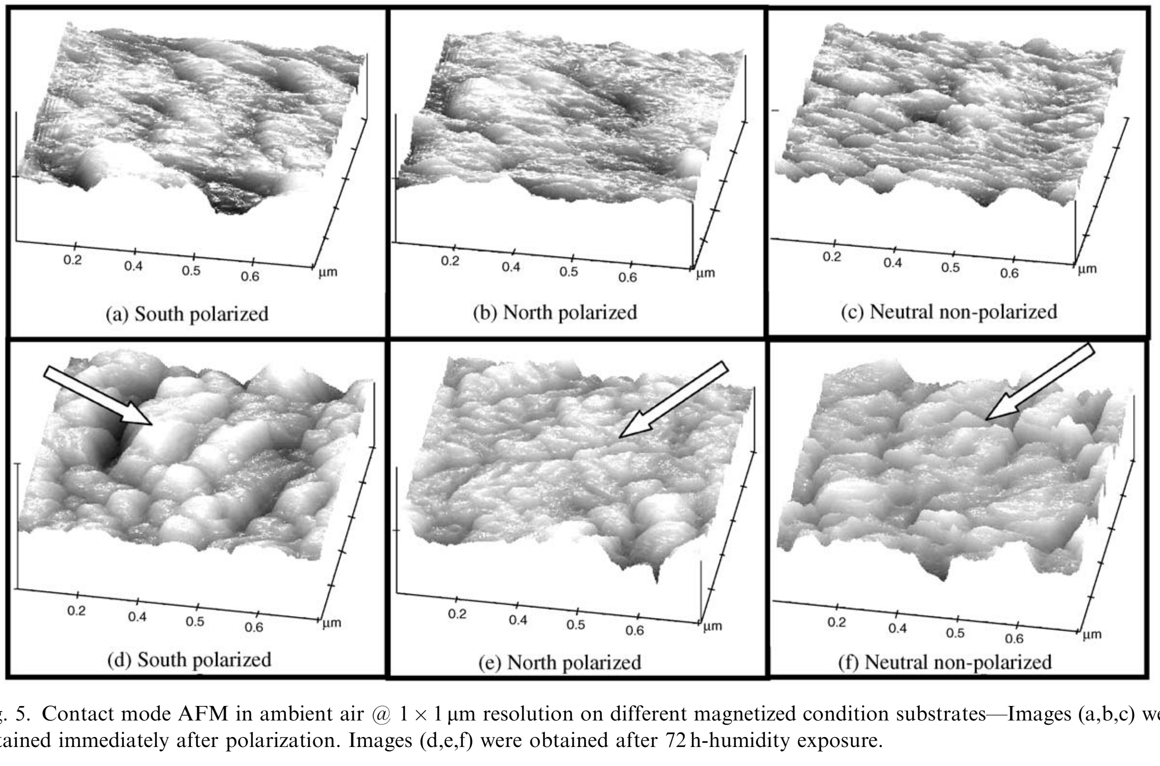

Fig. 5. Contact mode AFM in ambient air @ $1 \times 1\,\mu m$ resolution on different magnetized condition substrates—Images (a,b,c) were obtained immediately after polarization. Images (d,e,f) were obtained after 72 h-humidity exposure.

ized substrate appeared in a more swollen state as indicated by the arrows in Fig. 5(d). The swell size was approximately $0.2\,\mu m$ or smaller, with the average swell height and R_a increased to about 18 and 7.4 nm, respectively. For the north-polarized substrate, it appeared to have changed but to a more dehydrated state (as indicated by the arrows in Fig. 5(e)). The average swell height and R_a reduced to about 7 and 5.1 nm, respectively. As for the neutral non-polarized substrate (see Fig. 5(f)), the topographic image appeared in-between the north and the south polarized condition. Its swell height increased slightly to about 14 nm, and R_a increased to 5.8 nm.

The AFM topographic images in Figs. 4 and 5 suggest that the south and north-polarized substrates affect the moisture adsorption differently. In order to verify this and also to rule out the domain wall and crystalline structural movement from the magnetization process, we conducted two further tests. The tests were:

(i) Conducting the AFM imaging under liquid environment (tapping in liquid).
(ii) Measuring the contact angles of the sessile drop on the magnetically polarized and non-polarized substrates.

3.3. AFM in liquid imaging

The AFM measurement under liquid (distilled water) conditions using scan areas of 10×10 and $1 \times 1\,\mu m^2$ are as shown in Fig. 6. The south-polarized substrate (Fig. 6(a)) appeared more swollen over the entire surface as compared to the north polarized substrate (Fig. 6(c)). The $1 \times 1\,\mu m^2$ results for the south-polarized (Fig. 6(b)) substrate had shown a much increase in the swelling from previous 18 nm (seen in Fig. 5(d)), to about 24 nm. For the north polarized substrate (Fig. 6(d)), the swelling was less serious than the wetted south polarized substrate at 13 nm.

3.4. Contact angle measurement

Table 1 shows the results on the contact angles made between the distilled water droplet on substrates with differing magnetic states. The average values for contact angle for the south-polarized and north-polarized substrates are 96.55° and 102.67°, respectively, and this suggests a significant difference based on 1σ. The neutral non-polarized substrate gives rise to an average contact angles of 99.64°, which are in-between those of the two polarized state. Fig. 7 shows the distribution of the contact angles made between the droplet and the substrate.

The comparison of the results showed that the south-polarized substrate has a relatively higher

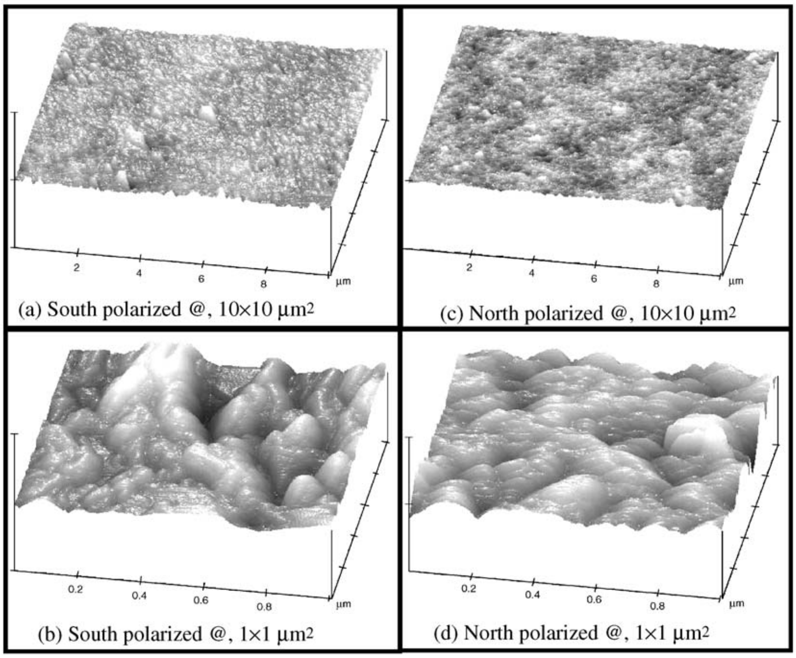

Fig. 6. Contact mode AFM in ambient air @ $10 \times 10\,\mu m^2$ and $1 \times 1\,\mu m^2$ resolution on different magnetized condition substrates (images rotated 10° and pitch angle 30°).

Table 1
Contact angle measurement

Substrate condition	Average water contact angle (deg)	Sample size, n
South-field polarized (S)	96.55 ± 1.19 (based on 1σ)	22
North-field polarized (N)	102.67 ± 1.05 (based on 1σ)	22
Difference (N–S)	6.12	—
Neutral non-polarized	99.64 ± 1.38 (based on 1σ)	22
Data error (repeatability)	0.39	20

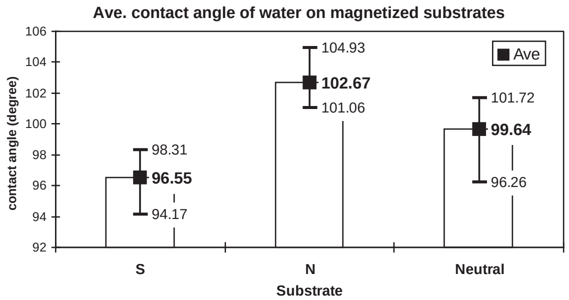

Fig. 7. Contact angle measurement on magnetic north and south polarized and non-polarized substrates (error bars denotes maxima and minima values).

degree of hydrophylic phenomenon as compared to the north polarized and non-polarized samples.

4. Discussion

4.1. SEM and Lorentz microscopy

The results in the SEM analyses have found no observed physical differences between the north-, south- and non- polarized substrates. The Lorentz microscopy was conducted to verify the magnetic state of the substrate. Since SEM was conducted under vacuum state, which eliminated the presence of water molecules in the substrates, the similarity of all the images for the three substrates indicated no physical changes to their microstructure. The presence of water molecules on the substrates was revealed from the AFM results.

4.2. AFM results

Prior to the 72 h-humidity exposure after the 1 h-magnetization process, the surface structures of the substrates with different magnetized conditions did not reveal any differences. However, the surfaces after the humidity exposure changed significantly between the north and south polarized substrates. These differences have indicated that there was an interaction between the different magnetized substrates with the environmental moisture. The swollen lumps and the increase in the surface roughness seen in the magnetically south-polarized substrate (spin down state) have indicated a lower surface energy, which caused the adsorption of water molecules into the organic-based polymers in the coating media. For the north polarized substrate (spin-up state), the topographic images appeared to be in the dehydrated state as compared to the south-polarized and non-polarized substrates. This suggests that the surface exhibited a higher surface energy, which has a tendency to repel moisture from the media.

To further validate this explanation, the AFM imaging was performed under liquid condition. The test results in the south-polarized substrate have shown that the minute lumps that appeared under ambient air have become enlarged when imaging was conducted under liquid conditions. The lumps appeared on the north-polarized substrate also showed similar behavior, that is an increase in the swell.

Based on the test conditions (conducted under ambient air and under liquid), the swell lumps on the south-polarized substrate were due to moisture absorption into the media. On the other hand, the north-polarized substrate showed a water repulsion behavior.

4.3. Contact angle measurement

The results on the contact angle measurement have found that the south-polarized substrate gave rise to a lower contact angle with water as compared to the north- and non-polarized substrates. This behavior has indicated that the magnetically south-polarized substrate is generally more hydrophylic as compared to the north- and non-polarized substrates. These results have re-enforced the earlier observation from the AFM and SEM analyses that water is actually being retained and subsequently being absorbed into the magnetically south-polarized substrate. In other words, the magnetic south field from a magnetized FD is able to retain water molecules and hence causing the organic polymers to absorb and subsequently swell to become more hydrophylic in nature.

As for the north-polarized substrate and the non-polarized substrate, the contact-angle difference has shown that the north-polarized substrate was generally more hydrophobic than the non-polarized substrate. This finding reaffirmed the earlier AFM findings on the north-polarized substrate having the tendency to repel moisture.

5. Conclusions

The perpendicular magnetic state in a horizontal magnetic recording media, such as the computer FD, has been found to interact with the environmental moisture. The magnetic surface of the south-polarized substrate (spin-down state) was found to be able to retain and adsorb water molecules into its coating media and on the contrary, the north-polarized condition (spin-up state) showed the exact opposite effect. As a result of this phenomenon, the physical surface condition and the surface hydrophobicity of a magnetized FD has been affected. These results have also demonstrated that the theoretical approach used to create this phenomenon could be valid.

The positive interaction with moisture from the south-polarized disk could become potential sites for fungus growth and may eventually affect the media's carrier stability and reduce the tribological performance. The findings indicate that a magnetic recording media will be prone to deterioration by moisture once it has been used for recording purposes.

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