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Mechanism of magnetic recording head contamination

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MECHANISM OF MAGNETIC RECORDING HEAD CONTAMINATION

A Thesis

Presented to

The Faculty of the Department of Materials Engineering

San Jose State University

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

by

Yanan Li

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APPROVED FOR THE DEPARTMENT OF MATERIALS ENGINEERING

Dr. Guna Selvaduray, Thesis Advisor

Dr. Kiumars Parvin, Reading Committee

Mr. Koji Shima, Akashic Memories Corporation, Reading Committee

APPROVED FOR THE UNIVERSITY

ABSTRACT

MECHANISM OF MAGNETIC RECORDING HEAD CONTAMINATION

by Yanan Li

The purpose of this study was to determine the mechanism of recording head contamination and its correlation to the recording head's electrical performance. This study focused on the contribution of disk design to contamination of recording heads. Smearing tests and Guzik electrical tests were employed. The origin of head contamination was determined to be primarily disk material, due to direct contacts between the recording head and media. The extent of recording head contamination was dependent on the carbon overcoat, roughness, cleanliness and texture of the disk. Degradation of the electrical signal, in terms of track average amplitude, was found to be asymptotically correlated to head contamination. Particles adhering to the head pole tip and the flying height change were the major reasons for degradation of electrical performance.

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CHAPTER 1

INTRODUCTION

The development of the electronic computer with the concurrent growth in information processing has created a tremendous demand for the automated storage and retrieval of masses of data. Digital magnetic recording elegantly serves this need and is now an exceedingly important field of applied magnetics.

Historically, the initial application of magnetic recording was for the recording and reproduction of sound developed by Valdemar Poulsen in 1899.⁽¹⁾ The work which ushered in mass data storage began to be firmly established since 1947 and the growth of data processing has since rapidly expanded. The first magnetic disk drive, the IBM 305, was introduced by IBM in 1957. It consisted of 50 double sided disks, 2 ft. in diameter, which could hold 5 Megabytes of memory. The latest disk drives consist of a single disk, 2.5 inches in diameter, and store more than 3 Gigabytes of data. The estimate of world wide shipment of disk drives for personal computers in 1994 was 64.0 million units and in 1997 it is estimated to grow to 116.8 million units.⁽²⁾

The boom in low-profile desktop computers, notebook computers, and now sub-notebook computers calls for a new generation of miniaturized disk drives. The growing demand is challenging the current technology for fabricating the rapidly shrinking media and read-write heads for the tiny drives. Also, new technologies for high-density disk storage are

being explored. There are four relevant areas of technical development: magnetic heads, magnetic recording surfaces, head-surface registration mechanics and read-write electronics.

Magnetic recording is based on the interaction between a magnetic storage medium and a magnetic head, in relative motion to one another. The magnetic head magnetizes the magnetic material traversing through a small region immediately adjacent when recording. The head provides an induced voltage on read-back, reflecting the rate of change of magnetization recorded on this magnetic "track." The rotating rigid disk for digital data storage applications was introduced in 1957.⁽³⁾ High reliability and magnetic data transfer rates were provided by a rapidly rotating rigid disk over which a magnetic read-write head moved in and out. Data were recorded as magnetic patterns written in circles around the hub of the disk. As shown in Figure 1, each of the concentric circles, called a track, was divided into a number of equal segments called sectors. Once the magnetic head was in position it would wait for the correct sector to rotate beneath it and then read or write data. Many refinements have occurred since 1957, but modern disk drives still operate under the same basic principles.

In magnetic hard drives the technology is moving toward contact recording, to achieve high areal recording density which requires the linear flux density^a and the track density^b to be as high as possible. The spacing^c between the head and medium must be made critically small to obtain a sufficiently large reproduced signal amplitude. For the medium

^a Linear flux density: number of flux reversals per unit distance.

^b Track density: number of tracks per unit distance.

^c Spacing: also known as clearance or flying height.

Figure 1: Schematic of data stored in sectors along tracks on disks.

and head, the surface flatness, roughness, cleanliness and friction properties are essential for obtaining the small spacing between the head and medium.

Future magnetic media technology trends include the use of alternate substrates in small diameter drives, employment of dual textured media to provide landing zones, and decrease in flying heights. The technology outlook for the hard disk areal density with the evolution of recording heads is shown in Figure 2.⁽²⁾ Magnetic heads have been developed from thin film inductive heads to magnetoresistive heads, and spin valve giant magnetoresistive heads. However, inductive thin film heads are expected to continue to be used for several years because they have some advanced properties such as better track registration than magnetoresistive heads. Pseudo - contact head technology has also been introduced to obtain higher signal outputs. When the head flies closer to the disk and ultimately even touches or slides along the disk surface, it could increase the possibility of head contamination. This will influence both the head's flying characteristics and sensitivity to flux and could potentially cause malfunctions on media performance, such as glide noise,^d error of electrical testing^e and miss-reading of heads.^f If the head continues to fly, the debris builds up on the head and sometimes retransfers back to the disk as a partially fused debris pile. These debris piles may cause severe head contact with the media until the disk coating or the head suspension is severely damaged.

^d Glide noise: high voltage amplitude and fluctuation when heads for glide testing are flying over the disk surfaces.

^e Error of electrical testing: such as error rate from Guzik electrical testing.

^f Miss-reading of heads: miss-read signals due to contamination.

Figure 2: The technology outlook for the hard disk areal density with the recording heads evolution.⁽²⁾

Contamination can be caused by a variety of processes, and an understanding of the head contamination process is necessary to improve yield and performance.

Contamination issues have become more important in magnetic recording hard drives with the decreasing spacing between the recording head and media. The objective of this study was to determine the mechanism of magnetic recording head contamination, and investigate the effect of contamination on the electrical performance, i.e., the amplitude of the recorded signal, of the hard drive. An understanding of the mechanism of recording head contamination is very useful not only for a better understanding of the head - disk interface, but also for improving the performance and reliability of hard drives. This study focused primarily on the contribution of disk design to recording head contamination. The effects of disk roughness, cleanliness, texture and lubricant on the performance of the recording head were also investigated.

The fundamentals of magnetic recording and a review of the pertinent studies in literature are presented in Chapter 2. The objectives of the investigation and experimental procedures employed are described in Chapters 3 and 4, respectively. The results obtained and discussion are contained in Chapter 5. The conclusions of this study and recommendations for future research are contained in Chapter 6. In order to assist the reader, a glossary of terminology is provided in Appendix A.

CHAPTER 2

BACKGROUND

2.1. Basics of Magnetic Recording

The principles of magnetic recording are based on the physics of magnetism, a phenomenon which relates to certain materials, which will be magnetized when placed in a magnetic field. Magnetism is a field manifestation of electricity in motion, such as an electric current in a conductor or the moving electrons of the atoms.⁽⁴⁾

The most common forms of magnetisms are: diamagnetism, paramagnetism, ferromagnetism, antiferromagnetism and ferrimagnetism. Ferromagnetism is the basis of the process of magnetic recording. The recording medium is ferromagnetic, as are the core of the recording and reproducing heads.⁽⁵⁾ Ferromagnetism arises in solids containing paramagnetic atoms when there is a strong positive coupling torque between adjacent atoms. The term “positive” stands for a torque which tends to align the moments in the same direction. This torque causes alignment even in the absence of an external magnetic field.⁽⁶⁾ Typical ferromagnetic materials are Fe, Ni and Co.

The field lines associated with a magnetic field (H) are called flux lines, given the symbol ψ . A stronger field has more flux lines running through a given area than a weak field, and the intensity is measured in terms of flux density (B), in units of weber/m² or tesla. Permeability (μ) is the magnetic property of a material which measures the induced flux

density (B) for a material when a magnetic field (H) is applied. Permeability is material dependent, and is defined as

$$\mu = B / H \quad [1]$$

while relative permeability is defined as:

$$\mu_r = \frac{\text{flux density in material}}{\text{Flux density in air}} \quad [2]$$

When a magnetic material is placed in a magnetic field (H), then the number of flux lines inside the material is flux density in air multiplied by its relative permeability (μ_r).

If the field strength is strong enough to saturate the material, then when the field is turned off, a certain amount of magnetism would remain; this is called the retention, or remanence (B_r). A field of the opposite direction is required for reduction of this remanence to zero, and the magnitude of this opposing field is named the coercive force or coercivity (H_c). A multivalued function, the hysteresis loop, results when the magnetization induction (B) is plotted in response to an applied magnetic intensity (H) in a ferromagnetic substance. Examples of both narrow and broad hysteresis loops are shown in Figure 3,⁽⁷⁾ as H is varied cyclically between equal and oppositely directed values. This results from the tendency of the saturated magnetic domains within the material to resist changes in orientation and alignment. The area of this loop is a measure of the energy expended during each cycle, to cause these changes within the ferromagnetic substance, and it is termed the hysteresis loss. The “soft” or readily magnetized materials exhibit relatively narrow loops in the H direction. This is an indication of easy magnetization and demagnetization and small hysteresis loss.

Figure 3: Hysteresis loop of magnetically soft and hard material.

In contrast, the magnetically “hard” or “permanent” magnet materials require large values of H for magnetization and demagnetization. They exhibit broad hysteresis loops. Magnetic recording heads require a magnetically soft material to easily generate the magnetic field with frequently changed applied electrical field. For the recording media, hard magnetic materials are favored, in order to keep the magnetization when the external field is removed.

The process of magnetic recording is illustrated in Figure 4. It is the process of magnetizing an extremely small volume of a thin material which has essentially the properties of a permanent magnet.

A schematic magnetic recording process which uses a ring type transformer with relative moving media is shown in Figure 5. The coil wound on the ring head is fed a current which carries the signal that needs to be written on the media; the magnetic field is then emitted from the head gap to magnetize the medium underneath. Due to the relative motion between the head and media, the temporal variation of a signal, the encoded version can be represented by spatial variations in magnetization along a recorded track. In the playback mode, the head will sense the magnetic flux change by the relative movement of the media, and this variation of flux will generate the voltage output in the head to represent the signals that are written on the track.

The application of magnetic digital recording in data storage is of great significance in current technology. In this case, the type of magnetic recording used is “digital”, that is, there are only two states of magnetization: one for a “1” bit and the other for a “0” bit.

Figure 4: Magnetic recording process.

Figure 5: Schematic drawing of magnetic recording process using a ring type transformer with relative moving media.

A schematic of the signals involved with digital magnetic recording is shown in Figure 6. The input data to a recording system is represented by pulses of current to a recording head. The input current, acting through the write head, switches the magnetization in a thin and close-spaced recording medium, such that the transitions in the state of the magnetization corresponds to the transitions in the input current. These pulses can be detected and represent the transitions in the input current.⁽⁶⁾

Generally, longitudinal recording in which the magnetization is in the plane of the recording film is the most popular type of recording. An alternative to this technology is vertical recording, in which the magnetization in the recording media is oriented perpendicular to the film surface. This requires a large perpendicular crystalline anisotropy, and the transitions are between “up” and “down” states of the magnetization. Longitudinally recorded magnetization, with low and high densities recorded is shown in Figure 7. Each bar represents a bit, or half a wavelength, which denotes the pattern that is written on the media. If the input signal carries a frequency f , and the media is moving at a velocity V relative to the head, then the wavelength λ recorded on the media can be presented as

$$\lambda = V / f \quad [3]$$

The linear density, D , is given by

$$D = 2 / \lambda \quad [4]$$

A higher density state can therefore be obtained by increasing the writing frequency and decreasing the relative velocity between the medium and the recording head.

Figure 6: A schematic Drawing of the signals involved with digital magnetic recording.⁽⁶⁾

Figure 7: Longitudinally recorded magnetization with low and high densities recorded.

2.2. Magnetic Recording Head

The transducer that converts electrical signals into magnetization patterns on the media is referred to as the "head". Writing is accomplished by magnetizing the media from the magnetic fields emitted from the narrow gap.⁽⁸⁾ In the writing process, the magnetic core in the head serves to generate a concentrated field. This field is limited by the saturation magnetization (M_s) of the head core material. Therefore the saturation magnetization M_s should be large. However, when the head is not energized, the field should be zero in order to avoid unwanted writing. This implies a low remanence. Finally, to avoid hysteresis losses, the coercivity should also be very small. Such low coercivity materials are said to be magnetically "soft." The hysteresis loop associated with the head material was shown in Figure 4.

The other desired properties for magnetically "soft" materials are high permeability, and high resistivity. High permeability reduces the required amount of core material for a given coercivity, and high resistivity reduces the eddy current losses. The names, compositions, and properties of many soft magnetic materials which could be useful in magnetic recording systems are listed in Table 1.⁽⁹⁾ Permalloy has been widely used in many magnetic recording and reproducing heads since it has a very small coercive force, thus permitting these heads with small magnetic gaps to demagnetize readily.

Table 1: Properties for magnetic "soft" material.⁽⁹⁾

Name	Symbol	Composition	Relative Permeability		Coercive Force	Saturation Induction	Hysteresis Loss/Cycle	Resistivity	Curie Temperature	Hardness
			Initial	Maximum						
			μ_i	μ_m	Hc amperes/ meter Oersted X 10E3/4 π	Bs webers/ meter ² Gausses X 10E-4	- Joules/ meter ³ ergs 10Xcm ³	ρ ohm-meter X10E8 microhm- cm	Tc °C	Rockwell "B" or "C"
	mks unit	Percent	X 10E-3	X 10E-3					°C	
	cgS unit	Percent	X 10E-3	X 10E-3					°C	
High purity iron		0.05 impurity	10	200	4	2.15	30	10	770	-
Si-Fe Grain		3.0Si	1.5	40	12	2	30	47	745	79-B
45 Permalloy		45Ni	2.5	50	24	1.6	120	45	400	-
4-79 Permalloy		4Mo 0.19Ni	20	100	4	0.87	20	58	460	62-B
Supermalloy		5Mo 0.19Ni	100	1000	0.16	0.79	0.8	65	400	-
Mumetal		5Cu2Cr77Ni	20	100	4	0.8	-	62	-	35-B
1040 alloy		3Mo14Cu72Ni	40	100	1.2	0.6	20	56	290	
Sendust		5Al, 10Si	6.5	25	8	0.9	-	200	500	48-C
Ferroxcube3		Mn-Zn-Ferrite	1	1.5	8	0.25	13	10 ⁻⁸	90	
Ferroxcube4		Mn-Zn-Ferrite	1.5-3.6	2.0-5.0	11.9-15.9	0.36-0.52	-	10 ⁻¹²	130	
2-81 permalloy powder		2Mo81Ni	0.125	0.13	-	0.7		10 ⁻⁶	480	

The most commonly used inductive heads for digital recording systems are based on the design of inductive coil and magnetic core. In many heads, the core is usually permalloy. The design of the head must conform to the design of the disk. A higher recording density requires smaller dimensions in gap length,⁸ track width, and core volume of inductive heads. The shrinking size of inductive recording heads recently is shown in Figure 8.⁽¹⁰⁾

Inductive heads can be designed to perform three major functions in magnetic recording: recording (writing), reproducing (reading) and erasing. For hard disk drive systems, one head is used to perform all the functions. In disk drives, the function of erasing is carried out by overwriting the previous information.

With an increase of recording densities, the read signal has been correspondingly reduced. With any type of inductive head, the head output falls off exponentially with the spacing that accidentally or intentionally existing between the active surface of the head and the medium. The equation describing this relations is:

$$\frac{e_d}{e_o} = \exp\left(-\frac{2\pi d}{\lambda}\right) \quad [5]$$

where the subscripts denote a spacing of d and a spacing of zero. “ e ” stands for the voltage output. The severity of this spacing loss increases rapidly with decreasing wavelengths as described by Equation [3], and the spacing loss is the dominant cause of loss at high densities.⁽¹¹⁾

⁸ Head gap length: is the discontinuity in the head (core) flux path which results in the gap fringe field.

Figure 8: The shrinking size of inductive recording heads recently.⁽¹⁰⁾

In order to attain high areal density and also obtain a sufficient signal output, the spacing between the head and medium has been significantly reduced recently. In some hard drives, the spacing has been reduced to 1 microinch. However, the small spacing between the head and medium will also increase the possibility of head contamination, and influence the electrical and mechanical function of the recording head in the hard drive.

A typical ring type head is shown in Figure 5. In hard disk drives, the head is mounted on a slider which flies above the rotating disk, and provides an air bearing which, in principle, avoids wear.⁽¹²⁾ The slider is designed such that an air bearing is formed between the head and medium. This hydrodynamic pressure supports the weight of the head and avoids the contact between the head and the medium. However, when the disk is not rotating at a sufficiently high speed such as during the starting and stopping of the rotating disk, the slider will be dragging on the surface, resulting in direct contact.

The "head" is generally a slider/flexure assembly, also called the Head/Gimbal Assembly (HGA). The slider is a combination of the read/write element and a slider body, which is mechanically machined to form an Air Bearing Surface (ABS) to provide air bearing pressure supporting the weight of the head during the flying. The flexure is the suspension system which allows the slider to gimbal freely around the load point, and applying a load force to counter-balance the air bearing pressure. The suspension assembly is made up of a base plate, load beam, and gimbal.^h The suspension and related components in a hard disk drive is shown in Figure 9. The head gimbal assembly components are shown in Figure

^h Gimbal: Suspension feature to which the slider is attached.

10.⁽¹³⁾ The base plate is the suspension component which is used for attaching the suspension assembly to the actuator. The load beam is the suspension component that contains a spring region and a rigid region to control the gram force and the deflection. The dimple is a formed spherical feature which serves as the pivot point for pitch and roll rotation in a flexure type of gimbal.

2.2.1. The Winchester Head

The Winchester head introduced by the International Business Machines Corporation in 1973 is shown in Figure 11. The side view of Winchester head is shown in Figure 12, and the fringe field of the Winchester head is shown in Figure 13.

Each Winchester head has three rails, or raised surfaces. A magnetic core with wire coiled around for writing and reading the data is located at the trailing end of the center rail. The two outer rails govern the flow of the air. The hydrodynamic force that results is sufficient to support a weight of 10 grams at a height of half a micrometer above the disk. The disks and the head assemblies in such a unit are sealed in a small "clean room" in which the air is continuously recirculated and filtered to exclude any dust particles larger than 0.3 micrometer in diameter. The head shown in Figure 11 is upside down; the rail-like surfaces of the head confront the disk at a distance of half a micrometer. A closer view of the electromagnet is shown in Figure 12. The width of the beveled part of the center rail corresponds to the width of a track of data.

Figure 9: Suspension and related components in a hard disk drive.⁽¹³⁾

Figure 10: The head gimbal assembly component.⁽¹³⁾

Figure 11: Diagram of a Winchester head.⁽¹⁴⁾

Figure 12: Side view of Winchester head.⁽¹⁴⁾

Figure 13: Fringe field of Winchester head.⁽¹⁴⁾

The fringe field of Winchester head that lies outside a gap in the core of the electromagnet is shown in Figure 13. The arrows show the orientation of the field; their lengths show the intensity of the field, which is the field that writes the data. The horizontal field strength is plotted as a function of the distance from the center of head.⁽¹⁴⁾

2.2.2. Thin Film Head

Further developments in ferrite magnetic heads for applications in rigid-disk drives have led to the introduction of magnetic thin film heads with ferrite cores. Thin film heads will generate stronger recording fields, thus improving the overwrite characteristics, and therefore increasing the recording density.

A thin film head which is also shown upside down is shown in Figure 14. It has no coil made of wire in its electromagnet. Instead, it employs a spiral film of electrical conductor, shown in Figure 15, as the coil. The core of the electromagnet is permalloy. The electromagnet is at the trailing end of a structure designed to generate a supporting aerodynamic force when a disk is spinning under it. The side view of a thin film head is also shown in Figure 15. The fringe field of the thin film head is shown in Figure 16. The steepness of the decrease of the field, at each side of the electromagnet's gap, determines the packing density of data on a disk - the steeper the decrease, the greater the packing density.⁽¹⁴⁾

Figure 14: A thin film Head.⁽¹⁴⁾

Figure 15: Side view of a thin film head.⁽¹⁴⁾

Figure 16: Fringe field of a thin film head.⁽¹⁴⁾

2.2.3. Magneto-Resistive (MR) Head

MR heads are flux-sensitive reproducing heads which depend on flux rather than the rate of change of flux, as is the case with inductive heads. As the areal density of rigid disks has been required to be higher and higher, recording heads have evolved from thin film to magnetoresistive (MR) type. A schematic drawing of a MR head is shown in Figure 17. The technology utilizes the change in resistance of a magnetic material as a function of the magnetization vector. The magnetoresistive sensing element is designed as a narrow thin-film stripe perpendicular to the plane of the recorded medium, with its length equal to the track width. When the element is located at the head surface, the wavelength response can be enhanced by placing magnetic shields close and parallel to the element. MR heads are “read only” devices and writing has to be done with an inductive element.⁽¹⁵⁾

MR heads have several advantages over thin film heads: high areal density (800 Mbits/sq. inch), feasibility of independent read and write trackwidths, possible high track densities and high amplitude at low linear velocities. However, inductive heads still have some advantages such as better track registration over MR heads; therefore inductive thin films heads are still widely used.

Figure 17: Schematic drawing of a MR head.⁽¹⁵⁾

2.3. Magnetic Media

Current technology utilizes media in the form of a magnetic layer (sometimes two layers) supported by a nonmagnetic substrate. The magnetic material of the medium can be a coating made of magnetic particles held in a plastic binder, or it can consist of a deposited film of metal or oxide.⁽¹⁶⁾ Magnetic particles held in a plastic binder are usually ferrimagnetic iron oxide, in the form of small, needle-shaped particles. Most deposited metal films consist of cobalt and chromium, which attain much higher magnetization with a very thin magnetic layer, as compared to other magnetic materials.

Plastic films are mainly used as a substrate for the media in applications for tapes and flexible disks, and metal or ceramic substrates have been used for drums and rigid disks. Tapes vary in width from less than 4 mm to over 50 mm, and in length from a cartridge roll of less than 1 m to a reel of over 3000 m. Flexible disks vary in diameter from 75 mm to 200 mm. Rigid disks range from 32mm to about 360 mm, and up to a dozen double-sided disks are rotated on a single spindle.⁽¹⁷⁾

Magnetic thin films are hard magnetic materials which require relatively large applied fields to become magnetized or to reverse their magnetization direction. The most common magnetic thin film media and their magnetic properties are listed in Table 2.⁽¹⁸⁾ These magnetically "hard" materials retain the magnetization when the applied field is removed. The magnetic thin films have different magnetic properties from those of the magnetic recording heads, which they are made of magnetically "soft" materials with low coercivity, low magnetic remanence, and high permeability. In contrast, magnetically hard materials

Table 2: Most common magnetic thin film media in industry.⁽¹⁸⁾

Material	Deposition Method	Orientation	Crystal Structure	Ms, KA/m	Hc, KA/m	S,S*
Co	OIE	IPA	hcp	1100-1400	60-120	
	NIE,SP	IPI	hcp	1100-1400	30-60	
Fe	OIE	IPA	bcc	1600	60-90	
	SP	IPI	bcc	1600	10	
Ni	OIE	IPA	fcc	400	20-28	
	SP	IPI	fcc	800		
Co-Ni	OIE	IPA	hcp-fcc	800-1200	30-70	
Co-Ni	SP	IPI	hcp	1000-1100	60	
Co-Fe	OIE	IPA	bcc	1400-1600	60-120	0.9,0.9
Co-Sm	NIE(e)	IPA	amorphous	500-1000	33-55	1,1
Co-Sm	SP	IPI	hcp	650	50-250	0.8,0.85
Co-P	EL,EP	IPI	hcp	800-1100	36-96	0.9,0.9
Co-Re	SP	IPI	hcp-fcc	500-750	15-58	0.9,0.9
Co-Pt	SP	IPI	hcp-fcc	800-1400	60-140	
Co-Ni-P	EL,EP	IPI	hcp-fcc	600-1000	40-120	0.8,0.8
Co-Ni:O ₂	OIE	IPA	hcp-fcc	300-400	80	0.7-0.8
Co-Ni-Pt	SP	IPI	hcp-fcc	800-1100	60-140	0.9,0.97
Co-Ni-W	SP	IPI	hcp-fcc	450	30-50	0.8,0.8
Co-Ni-Cr	SP	IPI	hcp	950	50-60	
Co-Cr-Ta	SP	IPI	hcp	420-950	55-150	0.8-0.9
Co-Cr-Pt	SP	IPI	hcp	400-800	56-160	
Co-Cr-Pt-B	SP	IPI	hcp	580	110-150	
Co-Cr-Pt-Ta	SP	IPI	hcp	500	110-175	
Co-Cr-Pt-P	SP	IPI	hcp	560	200	
Fe ₃ O ₄	NIE,SP	IPI	I.S	400	17-32	

OIE: oblique incident evaporation; NIE: normal incidence evaporation; SP: sputtered;

EL: electroless - plated; EP: electroplated.

IPA: in-plane anisotropic; IPI: in-plane isotropic.

hcp: hexagonal close-packed; fcc: face-centered cubic; bcc: body-centered cubic;

I.S.: inverse spinel.

have high coercivity, high magnetic remanence, and low permeability.

Magnetic thin films are deposited on non-magnetic substrates. The common structure of thin film media, which consists of a substrate, an nickel-phosphor layer, a magnetic layer, and a layer of carbon overcoat is shown in Figure 18. The magnetic layer is generally cobalt-nickel-tantalum, or cobalt-nickel-platinum, with a thickness of 20nm, and a coercivity of 1000 to 2500 Oe. A layer of chromium (50-80nm), between the magnetic layer and the nickel-phosphor layer, is usually deposited to control the magnetic properties of the recording layer and provides adequate adhesion. A carbon layer of 10 to 25 nm thickness is generally sputtered on top of the magnetic layer as the protection layer. Finally, a thin layer of fluorocarbon lubricant is applied to reduce disk friction.⁽¹⁹⁾

Aluminum-magnesium alloy substrates plated with a nickel-phosphor alloy are used for most hard disks. The purpose of the nickel-phosphor alloy is to improve the hardness of the substrate and smoothen the surface of the bare Al-Mg substrate. The Ni-P layers are typically 10 to 25 micron thick, are amorphous, and contain sufficient phosphorus (4-5 wt%) to make it nonmagnetic.⁽²⁰⁾

The substrate, after plating with Ni-P, is then machine-textured to roughen it to a controlled fine pattern. Because a higher areal density has a critical head-disk interface requirement, the problem of wear and crash is ameliorated by using smaller sliders and lighter slider-suspension loading.

Figure 18: A common structure of thin film media with flying head.

To address this issue, a narrow band of the disk, normally in the inner diameter region of the disks, is textured and used as the contact landing zone during starting and stopping. The rest of the disk, which consists of the data zone, is not contacted by the head. If the disk landing zone is too smooth, it will result in stiction problems which are related to the molecular bonding that arises at the head to disk interface. The disk also has to be free of asperities and contamination particles which may disturb the flying height of the head and cause signal loss. Also, defects in the media, such as depressions or pits, may cause problems in the head to medium spacing, and consequently, cause a modulation of the signal amplitude, as shown in Figure 19.⁽²¹⁾ The problem can be solved by depositing the Ni-P undercoat as a thick layer so that some of the substrate defects can be polished away. The mechanical polishing and surface-finishing techniques to remove the substrate defects and clean the disk surfaces is shown in Figure 20.⁽²²⁾

A new technology of texturing, using laser to produce bumps on the disk landing zone or contact start stop (CSS) zone has been developed. For laser textured disks, the well controlled bumps are generated by pulsed laser heating. A micro-graph of laser-generated bumps is shown in Figure 21. Generally, the bumps are generated after the Ni-P coating process, and the disk surface has already been mechanically textured into a smooth surface so that there is no difference between the CSS and data zone. The laser bumps are generated on the CSS region to a desired surface roughness specification.

Figure 19: Defects caused modulation of the signal amplitude⁽²¹⁾

(a) A reproduced signal with a string of missing pulses, along with two types of film defects which can produce the signal decreases.

(b) A portion of the film is missing.

(c) The magnetic film is present across the entire track, with no thickness variation, but the topography of a substrate pit is replicated by the film, causing a head-to-medium spacing variation.

(a)

(b)

Figure 20: Mechanical polishing and surface finishing techniques to remove the substrate defects.⁽²²⁾

(a) Side and top view of a free-abrasive polishing process for rigid disk preparation. This is a process used on the substrate and/or the undercoat intend to produce a smooth surface for the magnetic layer.

(b) Fixed-abrasive buffing of a disk, used on the substrate or undercoat to produce a desired uniform texture. A similar process may be used on the overcoat, with different pressure and buffing tape, to remove loose particles or asperities formed in the film deposition processes.

(Rossi, 1984)

Figure 21: Laser-generated bumps on the CSS zone of the hard disk. (magnification is 400)

The laser bumps result in better controlled CSS zone surface characteristics than mechanically textured disk surfaces, and a data zone that is generally smoother than that obtained by the mechanically textured CSS disks. A schematic flow diagram of the overall disk manufacturing process is shown in Figure 22.

The small spacing between the head and disk requires a smooth and clean disk surface. In disk processing, a final surface buffing process is used to remove the asperities on the disk surface. Disks are buffed with an abrasive polishing poly cotton tape with light pressure, similar to that shown in Figure 20. This process does not produce a surface texture, but it only removes asperities on the disk surface. A burnishing head is also used sometimes to remove the asperities on the disk surface.

2.4. Head / Disk Interface

The attainment of higher recording densities requires that surfaces should be as smooth as possible and the flying height be as low as possible. The ultimate objective is to run two surfaces in contact if the tribological issues can be resolved. Smooth surfaces lead to an increase in adhesion, friction and interface temperatures. Also, closer flying heights lead to occasional contact of high asperities to increase wear and cause head contamination. A fundamental understanding of the magnetic head-disk interface, both on a macroscopic and microscopic scale, is crucial for the continued growth of the magnetic storage industry.

Figure 22: Manufacturing process of rigid thin film disks.

In the hard disk drive, the recording head is designed to fly over the hard disk during steady operation to avoid direct contact between the head slider and disk surface. The separation between the head and hard disk is provided by the hydrodynamic action of the disk spinning. The air bearing design is optimized so that it is "thick" enough to prevent wear but "thin" enough to give strong signals. A schematic view of the head/disk interface of a typical magnetic recording disk drive is shown in Figure 23.⁽²³⁾ The head slider material for current generation of thin film heads is Al_2O_3 - TiC. Other materials such as ferrites and barium titanate have also been used. An alternative slider material under investigation is silicon carbide, which is very hard and durable. Environment, usage time, and contamination (external and wear debris) also play a significant role in the reliability and usable lifetime of the interface.

The smoother surfaces and lower flying height of the recording head results in a higher stiction force at the head/disk interface and an increased potential of head-to-disk interactions. Wear can also occur when the drive starts and stops, since the head contacts the disk at the relatively slower speed when the hydrodynamic air bearing is not well developed. Stiction, or high static friction, can occur due to meniscus or viscous effects, microcapillary evacuation, and changes in surface chemistry. Generally, any liquid that wets or has a small contact angle on surfaces will condense on the interface in the form of a spherical-shaped capillary condensate. The pressure inside the liquid films of the capillary condensate or preexisting film of lubricant can significantly increase the adhesion between solid bodies.

Figure 23: Schematic diagram of the head-disk interface.⁽²³⁾

A wet surface with meniscus formation is shown in Figure 24.⁽²⁴⁾

Frictional forces are caused by adhesion and deformation of the asperities on the surfaces. For most practical cases, adhesional friction is the primary contributor to friction forces.⁽²⁵⁾ Experimental data suggest that adhesion is primarily due to weak van der Waals forces. In most cases, the static friction force that must be overcome to initiate sliding is much larger than the kinetic friction force during sliding.

2.5. Literature Review

During normal drive operation, contacts between the asperities on the head slider and disk surfaces result in adhesive and impact wear, and generate debris. James C. Uy⁽²⁶⁾ studied the cross transfer of debris between the head and disk by using "Laser Asperity Detector," and proposed a qualitative model explaining the interface failure mechanism. It was found that gel-like smears were built up mainly on the tapers of the sliders. These gradually grew and extended forward and sideways. The debris was found to be parallel to the main portion of the slider rail. Sometimes they decreased or disappeared, but new ones showed up. This suggested that a scrubbing action took place on the rails, by the asperities on the disk.

It was proposed that in the early stages of flying, only a few large asperities were hit by the head slider, and when these asperity contacts exceeded the maximum shear stress at the disk subsurface, they may initiate a crack. When the pitch excursion is severe enough, the leading part of the head hits the disk, and the friction generates local heating.

Figure 24: Schematic of a wet interface with meniscus formation, showing, various forces being applied during sliding. F_M is the meniscus forces, W is the normal force, and F_A and F_S are the intrinsic friction force and the stiction force, respectively. ⁽²⁴⁾

It was predicted that the average and maximum transient temperature rise for a typical thin film disk-slider interface are 56°C and 81°C for an Al₂O₃ -TiC slider, and 77°C and 110°C for a Mn-Zn slider, respectively.⁽²⁷⁾ The size of an asperity contact is on the order of 1.5 µm in diameter. Since the duration of an asperity contact, at full operating speed, is less than 1 ms, the thermal gradients perpendicular to the sliding surfaces are very large. Repeated contacts would result in crack propagation (subsurface fatigue) leading to delamination of the overcoat and magnetic layer. Isolated contacts in a very clean environment generate very fine wear debris, which results in rather uniform disk wear from light burnishing.⁽²⁸⁾ The debris builds up on the head and sometimes transfers back to the disk as a partially fused debris pile. These debris piles, in turn, cause more severe head pitch excursions, and this cycle accelerates itself and eventually results in high friction and head crashes.⁽²⁶⁾

External contamination readily abrades the overcoat and results in localized damage to the disk surface by abrasion. Wear debris invades the spacing between the head slider and the disk and are transferred to the head slider making it unstable. This leads to additional debris and head crashes both in the start/stop and flying modes. Koka and Kumaran⁽²⁹⁾ found alumina contaminant particles build up in the leading-edge taper of the slider, which degraded the flyability of the slider and caused abrasive wear on the disk.

Engel and Bhushan⁽³⁰⁾ developed a head-disk interface failure model based on the topography of the wearing surfaces. The principal variables included sliding speed, surface topography, mechanical properties (i.e. hardness), coefficient of friction and wear rate.

Surface asperities and debris particles induced impact and sliding encounter, which represent a damage rate. Failure occurred when a specific damage rate, a characteristic for this type of disks, was reached.

Chandrasekar and Bhushan, Chu, and Koka⁽³¹⁾ studied the effect of slider material on the durability of the head-disk interface. The representative profiles of the coefficient of friction, as a function of the number of passes, for an un-lubricated thin film disk with a carbon overcoat sliding against various slider materials is shown in Figure 25. Single-phase slider materials were found to be more consistent in wear behavior than multi-phase slider materials. All multi-phase materials showed both slow and rapid increases in friction. In general, the single-phase slider materials showed lower wear than multi-phase materials. The differences in the wear behavior of materials were attributed to micro-structural flaws present in the multi-phase system.

The structure and properties of the overcoat on thin film disks play an important role in its durability. The dominant overcoat used in today's commercial media is a hard carbon. Khan⁽³²⁾ reported that hard-carbon overcoats with better wear performance have homogeneous grain size, uniform grain distribution and higher percentage of sp^3 bonded carbon atoms (diamond structure). Carbon films deposited by low energy processes, such as conventional diode sputtering, tend to form local atomic bonding similar to that in graphite (sp^2), rather than diamond (sp^3). Amorphous diamond-like carbon film, also known as I-carbon, refers to films in which there is substantial tetrahedral local bonding as in crystalline

Figure 25: Coefficient of friction as a function of the number of passes for an unlubricated thin film disk with a carbon overcoat sliding against various slider material.⁽³¹⁾

diamond. Such films normally require high energy ion bombardment during growth to obtain this coordination. Films deposited using PECVD can approach diamond-like carbon without high energy bombardment, but this has been used for recording media only in laboratory studies so far.

Two basic problems are associated with graphitic (sp^2) carbon overcoats: poor wear resistance and corrosion protection. The primary wear mechanism was found to be tribo-chemical. Under the action of friction, the carbon overcoat oxidized to produce CO and CO_2 in the presence of oxygen and water vapor.⁽³³⁾ Oxygen reacts with the surface carbon which has dangling bonds to form and adsorb CO and/or CO_2 , and activated by the heat and mechanical contact generated by the sliding motion of the head. This wear process creates smoother surfaces and higher stictional forces. Some evidence on the formation of a graphitic transferred film at the interface of some carbon films has also been found.⁽³⁴⁾ Graphitic carbon is also pervious to oxygen, allowing the cobalt alloy medium to oxidize. Cobalt oxide corrosion products diffuse through the carbon overcoat to the surface, where the head produces cobalt oxide smears, leading to disastrous head-disk interactions.

The solution to the wear and corrosion problems was to introduce dopants during the carbon deposition, thus saturating the carbon bonds. It is found that oxygen tends to react with the double (unsaturated) carbon bonds of the sp^2 structure. Saturating these bonds does not produce diamond-like carbon, but does retard oxidation and permeation to oxygen. Today's commercial carbon overcoats commonly incorporate hydrogen by introducing hydrogen or a hydrocarbon gas, such as methane, into the sputtering gas. Nitrogen

incorporation has also been shown to be an effective method of saturating, but is not widely used commercially yet.

Sputtered carbon without hydrogen incorporation is typically a semi-metal or semiconductor. The properties of three typical carbon films, with hydrogen content in the sputtering gas, are listed in Table 3.⁽³³⁾ The term aC:H indicates amorphous hydrogenated carbon and DLC indicates diamond-like carbon. Marchon⁽³⁴⁾ reported that the greatest improvement in hardness and scratch resistance was obtained with 5% H₂ in the Ar sputtering gas, and that films became soft for H₂ contents greater than 20%.

The performance of the head/disk interface also depends on the texture of the disk surface. The method of introducing texture lines on disk surfaces was explained in Section 2.3. Although magnetic thin film disk surfaces appear to be almost perfectly smooth when seen under a low power microscope, atomic force microscopy (AFM) shows that a typical disk surface is rough on a nanoscale. A typical AFM image of a hard disk surface is shown in Figure 26. The grooves and ridges are needed to provide a well-controlled amount of surface contact between the slider and the disk, thereby reducing friction during start-up of the disk drive when the slider is in contact with the disk. Commercially, the following statistical parameters are commonly used to characterize the surface roughness of a particular surface: roughness average (Ra), maximum profile peak height (Rp), maximum profile valley depth (Rv). These terms, and the manner in which they are deduced from surface profiler data, are presented in Appendix B.

Table 3: Properties of three hydrogenated carbon films.⁽³⁵⁾

Carbon Film Type	Hydrogen %	Youngs Modulus	Resistivity
C: graphic	8.2	106Gpa	10⁵ ohm-cm
αC:H	33.2	108Gpa	10¹³ ohm-cm
Diamond-like C	30.4	246Gpa	10¹¹ ohm-cm

Figure 26: Atomic force microscope (AFM) image of a thin film hard disk.

The tribological performance of the head/disk interface is not only determined by the overcoat, but by the lubricant as well. The friction behavior of an Al_2O_3 -TiC slider on unlubricated and lubricated disk surfaces is shown in Figure 27. It was found that the coefficient of friction increased much more rapidly with the number of cycles for an unlubricated disk than for a lubricated disk.⁽³⁶⁾ The most effective lubricants have been found to have a constituent bonding to the overcoat and a fairly mobile component to easily fill and repair the damaged lubricant area. These lubricants possess a functional end group, such as COOH , which electrostatically bonds to the over coat.⁽³⁷⁾ Static friction, or stiction, generally increases with adsorbed water vapor. Tian and Matsudaira⁽³⁸⁾ have reported that the thickness of adsorbed water is less for lubricated than non-lubricated surfaces. Smallen⁽³⁹⁾ reported that the amount of lubricant has little effect on the adsorbed water layer except when the hydrogen content of the overcoat is very low, i.e., less than 5%.

The lubricant thickness, viscosity and functionality, and the disk surface roughness play important roles on disk durability.⁽⁴⁰⁾ The thickness of the lubricant must be optimum to reduce the stiction and protect the interface. Generally, a sharp increase in the dynamic and static friction coefficients, across the interface, occurs after a critical film thickness was reached, due to strong adhesion across the interface. This lubricant thickness for the beginning of high friction forces was found to increase with increasing disk surface roughness, lubricant viscosity and head sliding speed. The various data suggested that the rate at which strong adhesion develops depends on the lubricant viscosity.⁽⁴¹⁾

Figure 27: Friction behavior of an $\text{Al}_2\text{O}_3\text{-TiC}$ slider on unlubricated and lubricated disks' surfaces.⁽³⁶⁾

Yanagisawa⁽⁴²⁾ and others have shown that polar lubricants spin off less than nonpolar lubricants during disk rotation. The dual-layer concept, with an unbonded layer over a bonded layer, is very useful since the unbonded (mobile) top layer would heal any worn areas on the disk surface where the lubricant may have been removed.

2.6. Summary of Background

The basics of magnetic recording were described in Section 2.1. By using magnetic materials, magnetic recording systems have been established. The process of magnetic recording is the process of magnetizing an extremely small volume of a thin material which has essentially the properties of a permanent magnet. By means of the writing and reading process through the magnetic head, the input signal is recorded and played back on the magnetic media. Inductive thin film heads have been widely used in digital recording systems, where the thin film materials of the inductive head have the properties of high permeability, high saturation flux density, high resistivity and low coercivity. The "head" is generally a slider/flexure assembly. The slider is a combination of the read/write element and a slider body that provides an air bearing, when the head flies over the rotating disks, by hydrodynamics, to avoid wear.

Magnetic thin film media are hard magnetic materials which consist of a substrate, an undercoat, a magnetic layer, and a layer of carbon overcoat. The substrate is machine-textured to roughen it to a required pattern for obtaining a critical head-disk interface. The

defects on the substrate are polished away by texturing. Laser texturing technology has been developed for controlled CSS zone texturing.

The attainment of higher recording densities requires smoother disk surfaces and lower flying heights of recording heads. The environment, usage time, and contamination play a significant role in the reliability and usable lifetime of the interface. The debris generated by the contacts between the head and the disk builds up on the head and sometimes transfers back to the disk as a partially fused debris pile; this cycle accelerates and eventually results in high friction and head crashes. This phenomenon holds true especially in the start/stop stage and unstable flying heights. Some head-disk interface failure models have been established based on the topography of the wearing surfaces. The sliding speed, surface topography, mechanical properties, coefficient of friction and wear rate are relevant parameters. The slider material and structures and properties of the overcoat on the thin film media also play an important role in the durability of the head/disk interface. Disk durability also depends on the lubricant thickness, viscosity and functionality, and the disk surface roughness.

CHAPTER 3

EXPERIMENTAL OBJECTIVES

The purpose of this study was to determine the mechanisms of recording head contamination, and investigate the effect of contamination on the electrical performance of the recording heads. This study was focused on the contribution of hard disk design to the contamination of the recording head. The effects of disk carbon overcoat, roughness, and cleanliness on contamination of the recording head were investigated. The effect of environment on disk performance was also studied. The effect of contamination on electrical performance (signal output) degradation, and the relationship of this degradation to head flying height and head contamination were also researched.

CHAPTER 4

EXPERIMENTAL PROCEDURE

The experimental approach for this study was divided into two parts: investigation of mechanisms of magnetic recording head contamination, and investigation of the effect of contamination on electrical performance of the recording head. The possible sources of contamination of the recording head are shown in Figure 28. Figures 29 and 30 are summaries of the procedures employed in the study of contamination mechanisms and influence of contamination on electrical performance of the recording head, respectively.

Disks made with different carbon overcoats and texturing were tested in the smearing test. The surface characteristic values for these disks are summarized in Section 4.1. The recording heads studied were pseudo-contact tri-pad heads.ⁱ Smearing test was the main method employed to evaluate the disks' surface properties, and to investigate the extent of contamination on the recording head. A Guzik head/disk analyzer was employed to study the change of electrical performance due to the effect of contamination on recording heads. A list of the equipment used in this study is contained in Table 4, and a list of the materials utilized is contained in Table 5.

ⁱ Pseudo-contact tri-pad head: Pseudo-contact means that when the head fly over the disk surface, it contacts the surface on and off; Tri-pad means that there are three pads on the slider, one is on the center of trailing edge, the other two are on the corner of the leading edge. The tri-pad design can provide the required air bearing and lead the contamination particles follow the air flow through the slider.

Figure 28: Flow chart of mechanism of magnetic recording head contamination.

Figure 29: Test matrix and experimental approach for study of mechanisms of contamination.

Figure 30: Effect of contamination on electrical performance of recording head.

Table 4: List of equipment.

Items	Description	Equipment Location
Akashic in-house smearing tester	Recording heads are placed on this tester to seek on the disk surfaces to accumulate contamination on heads	Akashic Memories Corporation
Optical Microscope	For inspection of head contamination	Akashic Memories Corporation
Atomic force microscope (AFM)	A nanoscale microscope for examining head contamination	Akashic Memories Corporation
P2 long scan profiler	For disks' roughness measurement	Akashic Memories Corporation
Guzik head/disk analyzer	Characterize the electrical performance of head/disk	Akashic Memories Corporation
Phase metrics head flying height measurement	Optical tools used to measure the flying height of recording head	Akashic Memories Corporation
Electron spectrometry for chemical analysis (ESCA)	Elemental chemical analysis for contaminants	Charles Evans & Associates

Table 5: List of materials.

Items	Description	Supplier
Recording heads	1 micro inch flying height tri-pad recording heads	Akashic Memories Corporation
95mm outer diameter magnetic hard disks	Rigid disks used for study	Akashic Memories Corporation

4.1. Study of Mechanisms of Head Contamination

4.1.1. Preparation of Specimen

Four sets of 95 mm thin film disks, Series A, B, C and D, and Perfluorated Contour Incorporated (PCI) mechanically good heads were used. The disks were made of Al-Mg/Ni-P substrate, coated with a magnetic layer of Co-Cr, a layer of carbon protection layer and lubricant layer. The A, B, C and D series had different carbon overcoats, textures and roughnesses, as listed in Table 6.

For each group of disks, half were tested as “ambient” disks,^j the other half were soaked in an environmental chamber kept at 60°C temperature and 80% relative humidity for 24 hours. The environmental chamber simulates the environment to the required environmental conditions and enables evaluation under specified temperature and humidity. The soaked disks are referred to as “hot/wet” disks, to be compared with “ambient” disks for their smearing performance.

Optical micrographs of a PCI head at magnifications of 37.5 and 300 are shown in Figure 31. It can be seen that the head is consisted of a slider body and read/write element (poletip). The z-height^k of the tri-pad heads were 25 mils based on head manufacturing criteria, and the disk was rotating at 4500 rpm during the test. The PCI head would thus attain a 1 μ inch flying height.

^j Ambient disks: Disks from manufacturing which are normally vacuum bag sealed without being exposed to hot or wet environment.

^k Z-height: The distance between the base plate of the head to the disk surface. The structure of the head refers to Figure 10.

Table 6: Physical Configurations of four sets of thin film disks employed for contamination study.

	Nitrogenated Carbon Overcoat	Hydrogenated Carbon Overcoat
Mechanically Textured (Roughness Ra 38Å)	A	B
Laser Textured CSS Zone (Roughness Ra 12Å)	C	D

Figure 31: Optical microscope pictures of PCI head at magnification magnification 37.5 and 300.

4.1.2. Smearing Test

A smearing tester was used to characterize the smearing performance of the PCI recording head. The “seeking” test mode was chosen, whereby the head would be seeking from the OD (1.71in) to ID (0.81in) back and forth at a speed of 0.4 in/min. The seeking sequence of OD→ID→OD was defined as being one seeking cycle. A schematic drawing of the smearing test is shown in Figure 32. 25 test cycles (approximately 100 minutes total testing time) was set up to be completed, and the amount and type of contamination accumulated on the recording heads was examined after the tests.

4.1.3. Examination of Head Contamination

The extent of head contamination was examined, after numbers of specific seeking cycles (1, 2, 5, 10 and 25 cycles), with an optical microscope and compared with clean (fresh) head surfaces. The smearing on the recording head was rated from 1 to 5, depending on the extent of contamination on the head surface area. A rating of 1 indicates the cleanest head with no contamination, and a rating of 7 indicates the dirtiest head. The criteria to define the smearing rate was based on the head surface area covered by the contaminants. The correspondence between smeared area and the smearing rate is listed in Table 7. An Atomic Force Microscope (AFM) was also employed to examine the head poletip profile after the smearing test. The poletip profile of a contaminated recording head is shown in Figure 33.

Disk rotating speed: 5400rpm
Head seeking speed: 0.4inch/min
Head Z height: 25mil
Seeking area: ID 0.78inch
OD 1.75inch

Figure 32: Schematic drawing of a medium and a head during smearing test.

Table 7: Definition of smearing rate based on area covered by contaminants.

Smearing rate	Percentage area covered by contaminants
1	0-10%
2	10-20%
3	20-30%
4	30-50%
5	50-70%
6	70-90%
7	>90%

Figure 33: AFM image of a contaminated head's poletip. (Contamination particulates are the white clusters accumulated on the poletip as shown by the red arrow)

In order to check the removability of the smearing on the recording head surfaces, chemical substances such as a disk lubricant solvent PF5060, Freon, Aceton, Alcohol and De-ionized (DI) water were employed. Some of the adhered contamination might be effectively cleaned with a Q-tip with these solvents

Electron Spectroscopy for Chemical Analysis (ESCA) was employed to determine the chemical composition of adhered smears and the origin of contamination.

4.1.4. Measurement of Disk Roughness

A P-2 Tencor Long Scan Profiler was used to measure the roughness of the disk surface. The surface was scanned with a 2 micron stylus to measure the surface profile. A total of 100 points on one track at the ID were chosen to measure the peaks, valleys and average roughness. The same track was measured after the disk was tested on the smearing testers. The disk profile change due to the smearing tests were characterized by roughness measurements.

4.2. Study of Effect of Contamination on Electrical Performance of Recording Head

4.2.1. Preparation of Specimen

Two sets of thin film disks, Series A and B, and PCI electrically good¹ tri-pad heads were used. The disks were made of Al-Mg/Ni-P substrate, coated with a magnetic layer of Co-Cr, a layer of carbon protection layer and lubricant layer. Series A consisted of mechanically textured disks with a data zone roughness Ra of 38 Å while Series B had a laser textured CSS zone with a data zone roughness Ra of 12 Å.

¹ Electrically good: means the recording heads conform the magnetic requirement of the disks.

The data zone of Series B was 26Å smoother, on the average than that of Series A. All of the disks were soaked in an environmental chamber at 60°C/ 80% RH for 24 hours and prepared for the tests.

4.2.2. Electrical Test

A Guzik head/disk interface analyzer, Model RWA1001, was used to characterize the electrical performance of the head/disk. The z-height of the tri-pad heads were 25mil, based on head manufacturing parameters. The disk was rotating at 4500 rpm during the test, and the tri-pad heads attained a flying height of 1 μinch. In order to observe the head contamination, the test mode was chosen as "seeking." Heads would be seeking from the OD (1.71in) to the ID (0.81in) back and forth at a speed of 0.5 in/min. The seeking sequence of OD→ID→OD was defined as one seeking cycle, and a total of 15 cycles would be completed for the electrical test. After 0, 1, 5, 10 and 15 cycles, two sets of signals (one high frequency and one low frequency) were written on a certain track. These signals were then read, and track amplitude analysis was done with the data. The high frequency voltage amplitude output at each of the cycles was compared with the value for cycle 0, to determine degradation.

4.2.3. Examination of Head Contamination

The extent of head contamination was examined, after predetermined numbers of cycles, with an optical microscope, at magnifications of 37.5 times and 1000 times. The head poletip profile after test was also examined by Atomic Force Microscopy (AFM) to determine the poletip contamination.

4.2.4. Measurement of Flying Height

The flying height was measured by using phase metrics, which is a technique of optical interferometry. The flying heights of the tested heads were measured on phase metrics at six different velocities, namely, 300, 400, 500, 600, 700 and 800 inches per second (IPS). The flying height variation over one circle was also measured. Flying heights were measured at five different locations: center trailing (CT), outer trailing (OT), inner trailing (IT), outer leading (OL), and inner leading (IL). The flying height at CT was chosen as the data to be compared since that is where the poletip, the read/write element, is located.

4.2.5. Measurement of Disk Roughness

The roughness of the disk surface was measured with a P-2 Tencor Long Scan. The stylus of the P-2 is 2 μm in diameter, and scans over the surface. The vertical resolution is 1 $\text{\AA}$, and the scan length was 200 μm with a speed of 50 $\mu\text{m}/\text{sec}$. The disk surface roughness was measured at the ID, MD and OD regions. For each area, the statistics of disk roughness, waviness, peak to mean line and valley to mean line were calculated, and are shown in Appendix B.

CHAPTER 5

RESULTS AND DISCUSSION

Head smearing was evaluated with an optical microscope, and an atomic force microscope. The extent of smearing was rated based on area covered by contaminants. The smearing rate of recording heads changed with the smearing test time, with the behavior being asymptotic in nature. The smearing behavior of the head was found to be related to the disk roughness, cleanliness, carbon overcoat and environmental effects. ESCA analysis was performed to determine the origin of contaminants, which were found to be primarily disk material. The disk profile was measured before and after the smearing tests, and the peaks on the disks were found to have been abraded. The electrical signal degradation also showed an asymptotic behavior with the head seeking time, and was mostly due to some large asperities on the disk surface worn out due to the contact between the head and the disk during the first few seeking cycles. Also, degradation tended to increase with disk roughness. The head flying height also affected the electrical performance of the head/disk.

5.1. Mechanisms of Head Contamination

5.1.1. Head Smearing

An optical micrograph of a tested head is shown in Figure 34.

Figure 34: Optical microscope image of contaminated head at 300 times magnification.

Smearing can be seen on the slider next to the trailing edge.

Smearing was found around the trailing edge of the head, where the flying height is lower than at other locations.

5.1.2. Characteristics of Smearing Rate of Recording Head vs. Smearing Test Time

The extent of smearing on the recording head was measured in terms of the smearing rate of the head. The smear on the recording head was inspected after the seeking test of the recording head, as described in Section 4.1.3. The smearing characteristics of the recording head during the smearing test are shown in Figure 35.

Three heads (Mech 9, E56 and E57) were used to characterize the smearing behavior, as a function of smearing test time. Contamination particles started to appear on the recording head surface during the early stage of the smearing tests, and as shown in Figure 35, the recording heads had a relatively high smearing rate during the first few test cycles. The smearing rate stayed stable later on and the change of rate was smaller than the initial change of smearing rate. The smearing rate (amount of contamination on head surface) as a function of smearing test time is asymptotic in nature. The mechanism of this behavior can be explained as follows.

The recording head has a greater probability of making contact with the disk surface during the early seeking, mainly due to the large asperities on the disk surface. This mechanical contact between the head and the media would cause both the head and the disk to wear. The debris generated by this contact would be transferred across the head/disk interface, eventually adhering on the surface of the recording head and causing contamination. The adhered contaminants on the head, in turn, increase the instability of

Figure 35: Smearing rate vs. smearing test time.

the flying characteristics of the recording head.

Contaminated heads would have an increased flying height and also increased fluctuation of flying height, which in turn creates more likelihood of contact between the slider and the media. The mechanical contact would not only knock off the contamination but also increase the likelihood of generating debris from the head and the media. The two effects now interact each other, and partially cancel out. Therefore, as can be seen in Figure 35, the smearing rate (amounts of contamination on head surface) stays stable after the initial seeking.

Another reason for a stabilized smearing rate is due to the smoothed disk surface after the initial seeking. The disk surface was smoothed by the interaction between the recording head and the media, mainly because the large asperities on the disk surface were worn out by the mechanical contact between the head and media during the early seeking. These two factors contribute to the asymptotic behavior of the smearing rate with smearing test time.

5.1.3. The Contribution of Disk Design To Head Contamination

The design of rigid disks can be expected to significantly influence the smearing performance of these disks. Different carbon overcoats, surface textures and cleanliness have different effects on smearing test result. For mechanically textured disks, nitrogenated carbon disks showed less smearing on the recording head than hydrogenated carbon disks. The results are shown in Figure 36.

Figure 36: Smearing comparison between H-C and N-C on mechanically textured disks.

At least eight surfaces were tested for each group. The smearing of the tested heads was inspected with an optical microscope and the smearing rates for each group were determined by averaging the rates from the individual surfaces. For mechanical texturing, the ambient disks did not show any significant difference in smearing rate between nitrogenated and hydrogenated carbon. The ambient disks had a consistently lower smearing rate than the hot/wet disks, which meant that the ambient disks had good smearing performance with both hydrogenated and nitrogenated carbon overcoat. Under ambient conditions, the hydrogenated disks showed a smearing rate of 1.6, whereas the nitrogenated ambient disks had a rate of 1.8. The difference between these two groups is not significant since the standard deviation for each of these groups are 0.9 and 1.2, respectively. For hot/wet exposure, hydrogenated disks had a smearing rate of 3.4, and the nitrogenated disks had a smearing rate of 2.6; the standard deviations of each of these two groups was 0.8 and 0.8. Since both standard deviation was no more than 0.8, it can be concluded that the difference in smearing rate for nitrogenated carbon and hydrogenated carbon is significant. The difference in smearing performance between the hot/wet and ambient disks is explained in Section 5.1.4. Nitrogenated carbon showed slightly better smearing results, most probably due to a relatively lower tendency for particles to adhere to the surface.

The smearing test results from the texture/cleaning matrix are shown in Figure 37. Both ambient and hot/wet disks were tested. Mechanically and laser textured disks, and different cleaning steps were compared at the same time.

Figure 37: Smearing comparison of nitrogenated disks vs. cleaning steps.

LZT: Laser Texture

Mech: Mechanical Texture

There were eight surfaces tested for each group. The smearing rate of each group was determined by taking the average for the eight surfaces. The standard deviation for each group is listed in Table 8, it can be seen that no standard deviations was more than 0.8. It was found that the disks had less smearing as progressive cleaning steps were implemented. This is most obvious for the mechanically textured nitrogenated disks. This suggests that the cleaning steps did indeed result in the cleanliness of the disk surface being enhanced. The most important result is that laser textured disks showed very good smearing results for both ambient and hot/wet conditions. Photo micrographs of heads exposed to smearing by a mechanically textured hot/wet disk and a laser textured hot/wet disk are shown in Figure 38. This suggests that smoother surfaces would provide good and stable smearing results. The disk surface cleanliness also contributes to the lower degree of smearing for the tested heads, by the cleaner surface resulting in less smearing on the recording head. Fewer particles or less smearing on the disk surface will reduce the possibility of head/disk contact, and thus reduce the possibility of the contaminants transferring between the head/disk interface and eventually less material adhered on the recording head slider or poletip.

Table 8: Standard deviations for testing results from the texture/cleaning matrix (referring to Figure 37).

	LZT N-C Amb	Mech N-C Amb	LZT N-C H/W	Mech N-C H/W
Clean 1	0.6	0.8	0.8	0.8
Clean 2	0.0	0.7	0.5	0.6
Clean 3	0.4	0.4	0.5	0.8
Clean 4	0.8	0.5	0.4	0.8

ally textured

extured hot/wet

Figure 38: Photo micrographs of heads exposed to smearing by a mechanically textured hot/wet disk and a laser textured hot/wet disk. Magnification is 37.5.

5.1.4. Determination of Origin of Head Contamination

ESCA was employed to analyze the head contaminants. Two PCI heads, which had been tested on mechanically textured disks, were analyzed. These two head were used since mechanically textured disks caused greater accumulation of smearing on the head surface than laser textured disks. Separate tests were carried out for ambient and hot/wet conditions. For each head, the head slider and poletip area were analyzed. The ESCA results are shown in Figure 39.

The majority of the contaminants were found to be carbon, oxygen and fluorine, all of which are disk materials. A small amount of head material such as aluminum and titanium were also present. Composition differences between ambient and hot/wet cases were not detected in this analysis. However, more cobalt was present in the hot/wet case than ambient case. Also there was more smearing on the head tested on hot/wet disks than on ambient disks.

The presence of more cobalt in the hot/wet case suggests that more cobalt appeared on the disk surface than in the case of the ambient disk. Cobalt on the head surface is due to direct contact between the head and disk. The cause of the presence of cobalt on the disk surface is most probably due to the hot/wet environment which is more prone to drive the cobalt to the disk surface. The presence of cobalt reduces the clearance between the head and disk, thus causing more direct contact and picking up more smearing on the head slider.

Figure 39: PCI heads contaminant ESCA analysis.

The analyzing depth for the examined heads were approximately 50Å in this investigation. The nature of the contaminants on the head slider and poletip, for the two heads tested, was also different. On the head slider area, the contaminants were in the form of a continuous thin film, whereas they appeared to be particulates on the poletip area. This observation is related to the slider air bearing design. The slider tends to pick up the lubricant from the disk to form a continuous thin film, and the poletip area is more likely to pick up the particulates.

As was shown in Figure 39, the majority of the contaminants were carbon, oxygen, and fluorine; the lubricant is also made up of primarily carbon, oxygen, and fluorine. By subtracting the lubricant constituents from the contaminants, a normalized contaminants data chart was prepared, and is shown in Figure 40. The subtraction was based on using fluorine as a reference, since the ratio of carbon to fluorine, hydrogen to fluorine and oxygen to fluorine for the given lubricant was constant. It was found that the lubricant contributes significantly to head contamination. After subtracting the contributions of the lubricant, there is still a significant amount of carbon and oxygen present as contaminants. From Figure 41, it can be seen that most of carbon is hydro-carbon with C=C and C-H bonding. This type of carbon suggests that the contaminants might be from the wear of the carbon layer from the disk or organic contamination from the environment. There was still a fair amount of oxygen in the contaminants, besides the oxygen arising from the lubricant. This is either due to the adsorbed oxygen on the head surface, or to the formation of oxidation products on the head surface.

Figure 40: Normalized ESCA analysis on PCI heads (subtracting lubricant from Figure 39).

Figure 41: ESCA spectra for carbon analysis of head contaminant.

5.1.5. Disk Profile Change Due to Smearing Test

The effect of the smearing test to the disk surface profile can be determined by comparing the disk surface profiles. The R_p , which is the peak to mean line, was compared for the tested surfaces. The statistical distribution of the R_p before and after the smearing tests is shown in Figure 42.

The average of R_p was reduced from 148 Å to 138 Å, and the standard deviation dropped from 26 Å to 20 Å as a result of smearing test. From Figure 42, it can be seen that some of the high peaks on the disk surface were removed during the smearing tests. This suggests that during the smearing tests there were mechanical contact between the tested disk and head, and this mechanical contact caused the high peaks on the disk surface to be abraded away. The R_p reduction due to smearing test correlates well with the ESCA analysis on the head contamination which suggested that the disk wear most probably contributes to the head contamination.

5.2. Effect of Contamination on Electrical Performance of Recording Head

5.2.1. Track Average Amplitude (TAA) Degradation

Electrical Guzik tests were performed to study the degradation behavior of the recording heads during the time of seeking. The typical behavior of TAA degradation with seeking cycles is shown in Figure 43.

Figure 42: Disk Rp change before and after smearing test.

Figure 43: PCI TAA HF degradation vs. seeking cycles.

TAA degradation shows an asymptotic behavior with head seeking cycles, degrading with the continuation of seeking, with the highest degradation rate occurring during the first few cycles. The maximum degradation rate does not change significantly with a continued increase in the number of seeking cycles, beyond the first 40 cycles. The asymptotic behavior can be explained as follows.

In the first few cycles during seeking, some of the high asperities on the disk surface are worn out due to contact between the head and disk surfaces. This initial "wear out" smoothens the disk surface and causes the highest wear rate in the first few seeking cycles. The debris generated in this early stage is then transferred between the head and disk interface, some of them being deposited on the head pole-tip and slider to cause head contamination. These contaminants that adhere on the head slider and poletip form mainly during the early stage of seeking, due to the maximum wear rate in the beginning. These contaminants may also accumulate during the later stages of seeking. Contaminated heads would have an increased average flying height and increased flying height fluctuations.

The flying characteristics of a contaminated head compared to a new head are shown in Figures 44 (a) and (b). The heads were measured on a Phase Metrics Flying Height Tester at different linear velocities, to compare the flying characteristics. The flying height fluctuation on one track was also measured. It can be seen from Figure 44(a) that the outer trailing edge and inner trailing edge flying heights increased when the head was contaminated.

Figure 44: (a) Flying characteristics of contaminated head comparing with new head.

(b) Flying height fluctuation of contaminated head on one track at different angular position.

The linear behavior of the flying height vs. the velocity has also changed when the head was contaminated. The contaminated head also showed an increased trend to fluctuate within one track on the disk surface, which is shown in Figure 44 (b). At different angular positions, (also referred to as sectors), the contaminated head fluctuates significantly over one revolution.

Flying height fluctuation creates a greater likelihood of contact between the slider and the high points of the disk surface. Debris generated by this contact would be transferred and accumulates on the head slider and the poletip. More contaminants on the poletip decreases the sensitivity of the pole to magnetic field changes and causes further degradation of the TAA.

5.2.2. TAA Degradation Difference among Different Disk Surfaces

From each disk series A and B, four disks (eight surfaces) were chosen to carry out TAA testing. Each series was assigned one PCI head to test the disks. Disk series B only had 7 surfaces available because one of the surfaces was damaged during handling. The results are shown in Figure 45.

Disk series B showed less degradation, and the track average amplitudes were relatively more stable than those of disk series A. Smoother surfaces appear to have better TAA performance, most probably because smoother surfaces have less chances of contact with the head, and therefore less contamination adheres on the head poletip and the slider.

(a) TAA degradation of one head over 8 different surfaces

(b) TAA degradation of one head over 7 different surfaces

Figure 45: TAA degradation difference between mechanically textured and laser textured

disks.

The asymptotic behavior seen in Figures 45 (a) and (b) is similar to that seen in Figure 42. This suggests that for both series of disks, there were very slight differences between surface to surface within the same group. Also, the results of a one head-one surface test (Figure 42) and a one head-multiple surfaces test (Figure 45) are very close to each other.

5.2.3. TAA Degradation Differences among Individual PCI Heads

Individual PCI heads showed different behavior, and this influenced the electrical testing results significantly. In this study, experiments had been designed to test different heads over one disk surface. Twelve heads were used to complete the tests. The experimental results are shown in Figure 46.

Individual PCI heads had different TAA degradation rates, with heads having higher initial TAA readings being more likely to have higher TAA losses. The relationship between TAA loss after 15 cycles and initial TAA reading are plotted in Figure 47. The recording head voltage output is a function of the head flying height, poletip cleanness, writing frequency, turns of head coils, etc. Since all the heads were tested under the same testing file, the TAA output is related primarily to the head flying height and head poletip cleanness. If the recording head started from the relatively higher reading, which suggests a lower flying height at the beginning, then there were also more direct contacts between the head and disk surfaces. Consequently, more contamination accumulated on the poletip to cause the signal loss.

Figure 46: TAA degradation test results by different PCI heads over one surface.

Figure 47: TAA degradation vs. initial TAA readings.

5.2.4. Correlation between Head Contamination and TAA Loss

The tested head slider and poletip were examined optically and with an AFM. The contamination was rated in a scale of 1 to 7 (clean to dirty) based on visual inspection of the area covered by the contaminants. Under optical microscope, most of the tested heads did not have much contamination on the slider. Poletip contamination was observed under higher magnification.

Particles adhering on poletip could be clearly seen from AFM images as shown in Figure 33. The particles were around 1 μm size or less. Contaminants analysis by ESCA showed that the major constituents of the contaminants were carbon, oxygen, fluorine, and some cobalt. These particles adhering on the top of poletip would influence the sensitivity of the head and cause signal degradation. The correlation of head poletip contamination with TAA loss is shown in Figure 48. Generally, TAA loss increases as the head poletip contamination increases. The cleaner the poletip, the lower the TAA degradation, and conversely, greater contamination rate of the poletip leads to a greater possibility of incurring higher electrical signal losses such as TAA degradation.

5.2.5. The Influence of Disk Surface Roughness on TAA Degradation

Disk roughness plays an important role in TAA degradation. Disk roughness was measured with a P-2 Tencor long scan profiler. The correlation of TAA degradation with respect to different disk roughness for individual PCI heads is shown in Figure 49. Higher disk roughness resulted in larger TAA degradation. Smoother disk surfaces provide less chance of contact between the disk and the head, thus reducing the chance of head

Figure 48: PCI heads poletip contamination vs. TAA percentage loss.

Figure 49: TAA degradation vs. surface roughness by individual heads.

contamination, and in turn lower TAA degradation. It can be seen from Figure 49 that rougher disk surfaces have higher TAA degradation, compared to smoother disk surfaces.

5.2.6. Correlation of PCI Head Flying Height with TAA Degradation

The flying heights of tested heads were measured on a Phase Metrics Flying Height Tester. While lower flying heights result in a higher signal output, it also increases the possibility of head/disk contacts to cause contamination and degradation. The influence of PCI head flying heights on TAA degradation is shown in Figure 50. If the head flying height is higher than the glide avalanche point,^m very little TAA degradation was observed. If the head flying height is lower than the glide avalanche point, the lower flying heights resulted in higher TAA degradation. This suggests that if the heads fly lower than the glide avalanche point, there are more possibilities of head/ media contacts, and debris generated by this contact are transferred across head/disk interface and appear on the head poletip with the result of degrading the head output.

^m Glide avalanche point: a flying height designed for rigid disk, if head is flying above this height, there is no hard head/disk interaction.

Figure 50: PCI head flying height vs. TAA degradation on mechanically textured surfaces.

CHAPTER 6

CONCLUSION

The origin of head contamination and possible mechanisms of head contamination were investigated. The possible causes of head contamination can be categorized as follows: environment, manufacturing and handling, head/disk interface. This study focused on the head/disk interface aspect, and the contribution of disk design to head contamination.

Disks with nitrogenated carbon overcoats showed better smearing performance than disks with hydrogenated carbon overcoat. Laser textured disks with smoother data zones showed good performance under both hot/wet and ambient conditions. From ESCA analysis, the sources of recording head contamination were determined to be primarily disk material, with a small amount of head wear debris mixed up with them. Compositional differences in contaminants from hot/wet disks and ambient disks were not detected. However, the amount of cobalt present in hot/wet cases was more than that for the ambient cases. The amount of smearing on the head slider also indicated that hot/wet disks show worse smearing performance than ambient disks, with more smearing being found on the head slider of heads tested on hot/wet disks. The presence of cobalt indicates that the clearance between the head and disk surface had been reduced, thus increasing the likelihood of direct contact between the head and disk, resulting in more contamination.

The contamination on the recording head began to form in the early stage of testing, and a model has been proposed to explain this behavior. The recording head has more

chances of contacting the disk surface during early seeking, which is due mainly to the presence of some large asperities on the disk surface, resulting in mechanical contact between the head and the media. The debris generated by this mechanical contact transfers across the head/disk interface and builds up on the recording head, thus causing contamination. The stabilized smearing rate after the initial seeking is due to the smoothed disk surface after the large asperities are removed. The mechanisms of debris transfer to the head is most probably due to direct contacts between the recording head and media.

The electrical performance (TAA degradation) of the recording head, due to head contamination, head flying height and disk roughness, were determined. TAA degradation shows an asymptotic behavior with the number of head seeking cycles. TAA degrades continuously during seeking, with the highest degradation rate occurring during the first few cycles. A model has been proposed to explain this asymptotic behavior. Some large asperities/contamination on the disk surface are worn out due to the contact between the head and the disk. This initial wear out corresponds to the highest wear rate in the first few seeking cycles. The debris generated by this interaction is transferred across the head and the disk surface and accumulates on the head poletip and slider. Contamination on the head occurs in the early stages of seeking, and particles may adhere or drop as the test continues. If contaminants adhere on the head poletip, the sensitivity of the head responding to the magnetic field will be decreased and results in TAA degradation. The finding of this study shows that more contamination will cause higher TAA degradation.

TAA degradation differences among individual PCI heads can be explained by the head flying height. A higher initial TAA reading results in a higher TAA loss, and the higher initial TAA reading is most probably due to a lower flying height to obtain such a high output. A lower flying height corresponds to higher TAA losses. If the head has a lower flying height, it has more chances of mechanical contact with the head. Debris generated by this direct contact will be transferred to the head poletip and causes TAA losses. The TAA degradation also shows an increasing trend with an increase in disk roughness.

Contamination has a major influence on the electrical performance of recording heads, especially when contaminants adhere on the head poletip. More contamination on the head will cause more TAA loss. For pseudo-contact heads such as PCI heads, a flying height lower than the glide avalanche point results in a high TAA loss due to contacts between the media and the head. A smoother disk surface is recommended for reducing TAA loss.

CHAPTER 7

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APPENDIX A

GLOSSARY OF TERMINOLOGY

ABS: Air bearing surface. The design of ABS on the head slider can provide the required air pressure to lift up the recording head while disk is spinning to prevent the excessive wear of head.

AFM: Atomic force microscope, a nanometer scale profiler, the surface topographies of specimen can be obtained by using tungsten tip scanning over the surface in the X-Y plane.

Burnish: To polish, buff, smooth or put on a finish. Historically accomplished by the application of very fine polishing material (e.g. polishing tape) and/or flying a head over the surface at a very low height.

Certify: To verify, assure, authenticate, accredit or confirm.

DI Water: De-ionized water.

Environmental chamber: This specific chamber stimulates to the required environmental conditions and enables evaluation under specified temperature and humidity.

ESCA: Electron spectroscopy for chemical analysis. ESCA is a general acronym which characterizes the analysis of elemental and chemical phenomena in specimen surface layers.

X-ray or ultraviolet photons in a primary beam of energy interact with surface adsorbates or surface layers in a specimen and eject inner shell photoelectrons with a characteristic energy. By measuring the spectrum of photoelectron emission from a sample, the electronic structure

of atoms and molecules can be elucidated. Elements can be detected from Li to U, detection limits are 0.01-1 at%, analysis depth is 10-100Å.

Glide: To slip, flow or slide. This test determines the slider-disk contact resulting from asperities, debris and texture anomalies using acoustic emission sensor mounted on the slider. This is commonly a piezoelectric transducer. The acoustic emission or "hits" produced when the slider impacts an asperity are registered as the slider in flight scans the entire surface of the disk.

Glide height: Glide height sets the fundamental flying height of a disk. It is primarily determined by disk geometrical parameters including surface roughness, circumferential waviness, radial curvature, and radial slope.

Glide noise: High voltage amplitude and fluctuation when heads for glide testing are flying over the disk surface.

Gimble: Suspension feature to which the slider is attached.

Head/disk Spacing: Also known as clearance or flying height, the spacing between the recording head and magnetic disks while disk spinning and head obtain enough air pressure to lift up.

Hc: Coercivity

Hm: maximum applied field

HGA: Head/Gimbal assembly.

IPS: Inch per second

Linear Flux Density: Number of flux reversals per unit distance

MR: Magnetoresistive

Ms: Saturation magnetization

PCI: Abbreviation of Perfluorated Contour Incorporated. One type of pseudo-contact tri-pad head.

Poletip: Poletip consists of magnetic recording material, the magnetizing field is emitted from poletip. While head is flying, poletip is facing to the magnetic media underneath and magnetize it. Normally the dimension of poletip is in the range of 3-5 micron.

Profile: The curve of intersection of the normal sectioning plane with the surface.

Pseudo-contact tri-pad head: Pseudo-contact means that when the head fly over the disk surface, it contacts the surface on and off; Tri-pad means that there are three pads on the slider, one is on the center of trailing edge, the other two are on the corner of the leading edge. The tri-pad design can effectively provide the required air bearing and lead the contamination particles follow the air flow through the slider.

R.H.: Relative humidity.

Roughness: The finer irregularities of the surface texture that usually result from the inherent action of the production process or material condition.

S: Remanence squareness $S = M_r(\infty) / M_s$

S*: Coercivity squareness $S^* = 1 - \frac{M_r(H_m) / H_c(H_m)}{dM / dH}$

Surface texture: The composite of certain deviations that are typical of the real surface. It includes roughness and waviness.

Track Density: Number of tracks per unit distance

Waviness: The more widely spaced component of the surface texture. Waviness may be caused by such factors as machine or workpiece deflections. Vibration, and chatter.

Roughness may be considered as superimposed on a wavy surface.

Z-Height: The distance between the base plate of the head to the disk surface.

APPENDIX B

SURFACE CHARACTERIZATION (ASME B46.1-1995)

1. Definitions related to surfaces

Surface - the boundary that separates an object from another object, substance, or space.

Nominal surface - the intended surface boundary (exclusive of any intended surface roughness), the shape and extent of which is usually shown and dimensioned on a drawing or descriptive specification. (See Figure A)

Real surface - the actual boundary of an object. Its deviations from the nominal surface stem from the processes that produce the surface.

Measured surface - a representation of the real surface obtained by the use of a measuring instrument.

2. Components of the real surface

The real surface differs from the nominal surface to the extent that it exhibits surface texture, flaws, and errors of form. It is considered as the linear superposition of roughness, waviness, and form with the addition of flaws.

3. Definition related to the measurement of surface texture by profiling methods

The features defined above are inherent to surfaces and are independent of the method of measurement. Methods of measurement of surface texture can be classified generally as contact or noncontact methods and as three-dimensional (area) or two-dimensional (profile) method.

3.1. Profile

Profile - the curve of intersection of a normal sectioning plane with the surface (See Figure A).

Figure A: Schematic diagram of surface characteristics.

Nominal profile - a profile of the normal sectioning plane with the surface.(See Figure A).

Real profile - a representation of the real profile obtained by a measuring instrument(See Figure A).

3.2 Reference mean lines

Mean line - the reference line about which the profile deviations are measured. The mean line may be determined in several ways as discussed below.

Least squares mean line - a line having the form of the nominal profile and dividing the profile so that, within a selected length, the sum of the squares of the profile deviations from this line is minimized. The form of the nominal profile could be a straight line or a curve. (See Figure B).

Figure B: Examples of nominal profiles.

Filter mean line - the mean line established by the selected cutoff filter and its associated analog or digital circuitry in a surface measuring instrument.

3.3 Peaks and Valleys, Height Resolution, and Height Range

Profile peak - the point of maximum height on a portion of a profile that lies above the mean line and between two intersections of the profile with the mean line. (See Figure C)

Figure C: Profile peak and valley.

Profile valley - the point of maximum depth on a portion of a profile that lies below the mean line and between two intersections of the profile with the mean line.

Profile irregularity - a profile peak and adjacent profile valley.

System height (z) resolution - the minimum step height that can be distinguished from background noise by a measuring system. This is a key specification for a measuring instrument. The system background noise can be evaluated by measuring the apparent rms roughness of a surface whose actual roughness is significantly smaller than the system background noise.

Height (z) range - the largest overall peak-to-valley surface height that can be accurately detected by a measuring instrument.

3.4 Length

Sampling length - the nominal interval within which a single value of a surface parameter is determined. It corresponds approximately to the longest spatial wavelength of profile deviation to be included in the profile analysis.

Evaluation length - the length over which the values of surface parameters are evaluated. For proper statistics it should contain a number of sampling length. (See Figure D).

Traversing length - the length of profile which is traversed by a profiling instrument to establish a representative evaluation length.

Figure D: Surface profile measurement length.

4. Definitions of surface parameters for profiling methods

Profile height function, $z(x)$ or $f(x)$ - the function used to represent the point-by-point deviations between the measured profile and the reference mean line (See Figure E)

Roughness average, R_a - the arithmetic average of the absolute values of the profile height deviations recorded within the evaluation length and measured from the mean line. As shown in Figure E, R_a is equal to the sum of the shaded areas of the profile divided by the evaluation length L , which generally includes several sampling lengths or cutoffs. For

graphical determinations of roughness, the height deviations are measured normal to the chart center line.

Analytically, R_a is given by

$$R_a = (1/L) \int_0^L |Z(x)| dx$$

For digital instruments an approximation of the R_a value may be obtained by adding the individual Z_i values without regard to sign and dividing the sum by the number of data points N .

$$R_a = (|Z_1| + |Z_2| + |Z_3| + \dots + |Z_N|) / N$$

R_a = Average deviation of roughness profile $Z(x)$ from the mean line

= Total shaded area / L

Figure E: Illustration for the calculation of roughness average

Root mean square (rms) roughness, R_q - the root mean square average of the profile height deviations taken within the evaluation length and measured from the mean line. Analytically, it is given by:

$$R_q = \left[(1/L) \int_0^L Z(x)^2 dx \right]^{1/2}$$

The digital approximation is:

$$R_q = [Z_1^2 + Z_2^2 + Z_3^2 \dots Z_i^2]^{1/2}$$

Maximum profile peak height, R_p - the distance between the highest point of the profile and the mean line within the evaluation length (See Figure F)

Maximum profile valley depth, R_v - the distance between the lowest point of the profile and the mean line within the evaluation length (See Figure F)

Maximum height of the profile, R_t - the vertical distance between the highest and the lowest points of the profile within the evaluation length (See Figure F).

$$R_t = R_p + R_v$$

GENERAL NOTE: The mean line is denoted by M .

Figure F: R_t , R_p and R_v Parameters.

Waviness height, W_t - the peak-to-valley height of the modified profile from which roughness and part form have been removed by filtering, smoothing, or other means. The measurement is to be taken normal to the nominal profile within the limits of the waviness evaluation length.

APPENDIX C

Typical Test Raw Data

(1) P-2 Tencor surface profiler surface roughness

(2) Guzik RWA1001 TAA raw data

P-2 Tencor surface profiler surface roughness

Tensor Profiler Sequence Data
Tue Nov 19 14:50:54 1996

a 1-14
b - 3-66

Notes :
Run : #
Product : #
Layer : #
Operation : #
Operator : #
Lot # : #
Part ID : #070-AMS-1A
Sequence ID : 05M0104

AMC/DMECH

Recall: 45-PRODUCTS Unit: Angstroms No. of Locations:

	R1	R2	R3	R4	R5	R6	R7	R8
Mean :	-49	33	43	102	-133	27	24	175
Std. :	50	1	1	10	27	21	13	47
Min. :	-57	24	44	103	-134	13	27	127
Max. :	43	35	43	121	-127	41	31	212
Range:	105	2	1	17	43	28	21	89
LOC								
1	-57	25	43	141	-127	41	33	212
2	-57	25	43	140	-124	13	23	194
3	43	34	44	123	-123	23	27	127

Tensor Profiler Sequence Data
Tue Nov 19 16:10:32 1996

Notes :
Run : #
Product : #
Layer : #
Operation : #
Operator : #
Lot # : #
Part ID : #070-MS-1a
Sequence ID : 05M0104

Recall: 45-PRODUCTS Unit: Angstroms No. of Locations:

	R1	R2	R3	R4	R5	R6	R7	R8
Mean :	-43	37	42	100	-122	17	21	100
Std. :	44	2	1	15	25	1	1	27
Min. :	-49	25	43	114	-122	13	20	121
Max. :	-14	33	43	143	-140	17	21	103
Range:	35	8	1	29	43	4	1	82
LOC								
1	-44	35	43	133	-122	17	21	103
2	-73	33	43	142	-140	17	21	262
3	-43	37	42	114	-172	13	20	121

Tensor Profiler Sequence Data

Tue Nov 17 10:12:00 1992

Notes :
 Fab : #
 Product : #
 Layer : #
 Operation : #
 Operator : #
 Lot # : #
 Part ID : #073-AMS-29
 Sequence ID : 95M310A

AMC/OMEGA

Recipe: 95-PRODUC7A Unit: Angstroms No. of Locations:3

	Rt	Ra	Rb	Rc	Rv	Wa	Wb	Wc
Mean :	-15	36	46	130	-160	42	55	445
S.D. :	55	2	2	7	6	11	44	190
Min :	-91	34	44	126	-166	17	29	245
Max :	29	38	48	134	-151	79	100	561
Range:	106	4	4	8	16	62	71	316
Loc								
1	-91	36	46	126	-167	79	100	561
2	29	34	44	134	-156	31	4	215
3	5	37	48	132	-151	17	21	216

Vendor Profiler sequence data
 Tue Nov 17 20:34:27 1992

Notes :
 Fab : #
 Product : #
 Layer : #
 Operation : #
 Operator : #
 Lot # : #
 Part ID : #073-AMS-29
 Sequence ID : 95M310A

Recipe: 95-PRODUC7A Unit: Angstroms No. of Locations:3

	Rt	Ra	Rb	Rc	Rv	Wa	Wb	Wc
Mean :	-7	36	46	154	-154	54	72	575
S.D. :	174	2	2	30	39	11	12	45
Min :	-207	36	46	121	-129	56	72	461
Max :	110	39	51	176	-157	77	90	557
Range:	321	3	5	55	72	21	18	96
Loc								
1	110	39	46	166	-157	69	72	561
2	36	39	51	176	-229	55	71	557
3	-207	36	46	121	-166	77	91	457

Tensor Profiler Sequence Data
Tue Nov 19 20:49:33 1996

Notes :
Fab : #
Product : #
Layer : #
Operation : #
Operator : #
Lot # : #
Part ID : 4073-AMS-3A *AMC/OMEGA*
Sequence ID : 95NM310A

Recipe: 95-PRODLOCFA Unit: Angstroms No. of Locations: 8

	R1	R2	R3	R4	R5	R6	R7	R8
Mean :	3	32	43	133	-125	25	33	153
S.D. :	42	3	2	2	41	10	13	39
Min :	-40	13	41	133	-214	17	21	121
Max :	41	33	47	137	-102	37	50	426
Range:	81	20	6	4	75	20	29	304
LOC								
1	-40	13	46	133	-214	37	51	426
2	42	33	40	137	-134	25	30	153
3	15	33	47	133	-155	17	21	121

Tensor Profiler Sequence Data
Tue Nov 19 20:57:45 1996

Notes :
Fab : #
Product : #
Layer : #
Operation : #
Operator : #
Lot # : #
Part ID : 4073-AMS-3B
Sequence ID : 95NM310A

Recipe: 95-PRODLOCFA Unit: Angstroms No. of Locations: 8

	R1	R2	R3	R4	R5	R6	R7	R8
Mean :	27	32	45	149	-173	41	47	115
S.D. :	42	3	4	6	7	33	41	119
Min :	-51	33	40	133	-173	17	21	111
Max :	47	39	51	143	-165	55	46	574
Range:	118	6	11	10	17	37	25	462
LOC								
1	-51	39	50	140	-173	55	46	574
2	47	31	40	135	-173	20	24	161
3	46	33	45	140	-165	19	21	111

Tencor Profilometer Sequence Data
Tue Nov 19 21:09:30 1996

Notes :
Part : #
Product : #
Layer : #
Operation : #
Operator : #
Lot # : #070-AMS
Part ID : #L-MS-1A
Sequence ID : 95MM3104

Retline: 95-PROD007A	Unit: Angstroms				No. of Locations: 10			
	40	45	50	55	60	65	70	75
Mean :	-140	36	47	150	-126	34	41	150
S.D. :	11	1	1	26	1	1	16	11
Min :	-116	37	46	126	-100	33	40	116
Max :	-54	35	48	174	-126	37	41	164
Range:	62	1	2	48	26	4	7	48
LSC								
1	-54	35	46	151	-100	33	41	151
2	-100	36	46	174	-126	37	40	116
3	-116	37	47	126	-100	37	41	116

Tencor Profilometer Sequence Data
Tue Nov 19 21:11:11 1996

Notes :
Part : #
Product : #
Layer : #
Operation : #
Operator : #
Lot # : #070-AMS
Part ID : #L-MS-1B
Sequence ID : 95MM3104

Retline: 95-PROD007A	Unit: Angstroms				No. of Locations: 10			
	40	45	50	55	60	65	70	75
Mean :	-144	36	46	140	-126	32	41	150
S.D. :	70	1	1	6	17	6	6	24
Min :	-124	34	44	134	-126	31	38	137
Max :	10	36	46	146	-126	32	41	150
Range:	117	2	2	12	20	1	3	13
LSC								
1	-121	35	45	133	-126	31	38	133
2	-124	35	45	134	-126	32	39	137
3	10	34	44	146	-126	34	40	150

Tensor Profiler Sequence Data
Tue Nov 19 21:25:25 1996

Notes :
Part : #
Product : #
Layer : #
Operation : #
Operator : #
Lot # : #077-046
Part ID : #04113-24
Sequence ID : 95NM0104

Recipe: 95-PROD007A Unit: Angstroms No. of Locations: 7

	Rt	Ra	Rb	Rc	Rv	As	Ac	TIP
Mean :	-57	35	45	121	-153	17	17	112
Std. :	35	7	7	7	22	5	5	35
Min :	-57	35	45	113	-177	17	17	109
Max :	-11	35	47	129	-135	17	17	159
Range:	46	0	2	16	42	0	0	50
LOC								
1	-57	35	47	122	-151	22	17	159
2	-52	35	41	115	-135	17	17	125
3	-10	35	45	117	-177	17	17	107

Tensor Profiler Sequence Data
Tue Nov 19 21:31:41 1996

Notes :
Part : #
Product : #
Layer : #
Operation : #
Operator : #
Lot # : #077-046
Part ID : #04113-25
Sequence ID : 95NM0104

Recipe: 95-PROD007A Unit: Angstroms No. of Locations: 7

	Rt	Ra	Rb	Rc	Rv	As	Ac	TIP
Mean :	45	35	47	141	-153	17	17	142
Std. :	35	7	7	14	21	5	5	35
Min :	-49	35	45	130	-191	17	17	104
Max :	107	35	48	151	-145	17	17	184
Range:	156	0	3	21	46	0	0	80
LOC								
1	73	35	45	151	-191	17	17	184
2	-49	35	45	130	-150	17	17	102
3	107	35	45	140	-145	17	17	184

Tencor Profiler Sequence Data
Tue Nov 19 21:44:11 1996

Notes :
Fab : #
Product : #
Layer : #
Operation : #
Operator : #
Lot # : #N73-4X6
Part ID : #01-13-14
Sequence ID : 95M0104

Recipe: 95-PROD017A Unit: Angstroms No. of Locations: 3

	R1	R2	R3	R4	R5	R6	R7	R8	TOT
Mean :	4	36	44	117	-162	34	42	42	354
S.D. :	44	7	7	7	27	21	27	27	69
Min :	-39	30	41	114	-191	18	18	18	331
Max :	45	37	48	121	-138	58	68	68	422
Range:	87	7	7	7	54	40	49	49	111
LOC									
1	3	36	48	121	-138	18	28	28	421
2	-34	31	41	117	-168	25	18	18	379
3	42	35	44	114	-192	18	27	27	331

Tencor Profiler Sequence Data
Tue Nov 19 21:44:16 1996

Notes :
Fab : #
Product : #
Layer : #
Operation : #
Operator : #
Lot # : #N73-NMS
Part ID : #01-13-15
Sequence ID : 95M0104

Recipe: 95-PROD017A Unit: Angstroms No. of Locations: 3

	R1	R2	R3	R4	R5	R6	R7	R8	TOT
Mean :	-81	36	45	139	-159	21	37	37	351
S.D. :	51	7	7	11	51	5	7	7	68
Min :	-115	35	44	125	-145	12	21	21	328
Max :	-115	37	47	151	-157	27	34	34	452
Range:	55	2	3	24	51	15	13	13	124
LOC									
1	-115	35	44	131	-151	12	21	21	328
2	-107	36	45	139	-157	21	32	32	351
3	-115	37	47	129	-145	27	34	34	452

Tencor Profiler Sequence Data
Tue Nov 19 21:45:01 1996

Notes :
Fab : #

Product : 4
 Layer : 4
 Operation : 4
 Operator : 4
 Lot # : 4073-014
 Part ID : 40-410-14
 Sequence ID : 95MNC104

Recipe: 40-PROD007A Unit: Angstroms No. of Locations: 0

	R1	R2	R3	R4	R5	R6	R7	R8
Mean :	-35	34	40	122	-152	30	25	109
S.D. :	55	-	1	4	24	7	5	35
Min :	-70	33	41	115	-170	13	15	137
Max :	24	35	45	127	-145	25	33	137
Range:	95	2	4	12	125	12	18	100
LOC								
1	-69	35	44	127	-151	10	25	111
2	25	33	41	115	-145	10	15	137
3	-70	35	45	127	-150	12	33	130

Tender Profiler Sequence Data
 Tue Nov 10 22:00:57 1992

Recipe : 4
 Layer : 4
 Operation : 4
 Operator : 4
 Lot # : 4073-014
 Part ID : 40-410-14
 Sequence ID : 95MNC104

Recipe: 40-PROD007A Unit: Angstroms No. of Locations: 0

	R1	R2	R3	R4	R5	R6	R7	R8
Mean :	30	36	45	146	-155	22	17	145
S.D. :	157	4	5	24	12	4	4	51
Min :	-157	32	41	119	-170	15	11	107
Max :	167	39	50	163	-145	25	21	155
Range:	324	7	9	44	12	10	10	48
LOC								
1	163	37	50	163	-170	22	11	145
2	34	32	41	119	-145	15	11	107
3	-157	39	47	157	-155	15	21	155

Tandem Profiler Sequence Data
Tue Nov 19 22:14:11 1996

Notes :
Fac : #
Product : #
Layer : #
Operation : #
Operator : #
Lot # : 8075-12
Part ID : 40-118-12
Sequence ID : 95M0102A

Recipe: 95-PRODUT4	Unit: Angstroms				No. of Locations:3			
	40	42	46	48	49	49	49	715
Mean :	33	48	48	147	-170	22	31	160
S.D. :	37	2	2	3	27	2	3	48
Min :	-55	47	47	112	-184	40	18	111
Max :	40	40	47	151	-184	40	47	151
Range:	141	2	2	39	31	2	29	89
LOC								
1	-55	37	47	141	-141	24	18	141
2	71	38	48	151	-178	21	18	157
3	32	40	48	112	-184	22	28	111

Tandem Profiler Sequence Data
Tue Nov 19 22:19:53 1996

Notes :
Fac : #
Product : #
Layer : #
Operation : #
Operator : #
Lot # : 8075-12A
Part ID : 40-118-12
Sequence ID : 95M0102A

Recipe: 95-PRODUT4	Unit: Angstroms				No. of Locations:3			
	40	42	46	48	49	49	49	715
Mean :	-55	37	47	124	-200	21	18	170
S.D. :	134	2	2	2	22	2	10	42
Min :	-207	38	44	116	-204	21	17	110
Max :	52	39	50	131	-175	37	48	141
Range:	263	1	6	15	41	16	31	111
LOC								
1	-207	38	50	121	-204	37	47	141
2	-27	38	47	124	-175	32	48	138
3	52	39	44	116	-167	21	27	110

Guzik RWA1001 TAA raw data

*** TRACK ANALYSIS ***

ID: AMBR3-1 04/01/97 12:37:43 TRACK # 6070 HEAD # 0

| Write Current: 10mA | Period: 15.02nS | Overwrite Frequency: 5.50MHz |

HI FREQ AMPLITUDE	=	176.uV	LO FREQ AMPLITUDE	=	271.uV
NEGATIVE MODULATION	=	-15.26%	POSITIVE MODULATION	=	14.98%
RESOLUTION	=	64.78%	PULSE WIDTH	=	20.67nS
			OVERWRITE	=	25.92db
ASYMMETRY NEGATIVE	=	.69nS	ASYMMETRY POSITIVE	=	-1.63nS

***SYSTEM ID:RWA123 DRIVE ID:AMBR3-1 Date: 04/01/97 Time: 12:41:00 ***

*** MULTI ZONE #: 2 ***

Radius maximum	=	1.79 in	Rotational speed	=	5197. rpm
Track density	=	6410. tpi	Recording span	=	.95 in

Encoded Data:

BPI at inner trk	=	291360. bpi	BPI at curnt trk	=	125916. bpi
Drive capacity	=	1167.93 MGb	Bytes per track	=	192220.
Bit cell	=	7.51 nS			

Decoded Data:

BPI at inner trk	=	194240. bpi	BPI at curnt trk	=	83944. bpi
Drive capacity	=	778.62 MGb	Bytes per track	=	128147.
Bit cell	=	11.26 nS			

*** TRACK ANALYSIS ***

ID: AMBR3-1 04/01/97 12:47:57 TRACK # 6070 HEAD # 1

| Write Current: 10mA | Period: 15.02nS | Overwrite Frequency: 5.50MHz |

HI FREQ AMPLITUDE	=	191.uV	LO FREQ AMPLITUDE	=	296.uV
NEGATIVE MODULATION	=	-12.65%	POSITIVE MODULATION	=	14.11%
RESOLUTION	=	64.51%	PULSE WIDTH	=	20.74nS
			OVERWRITE	=	28.55db
ASYMMETRY NEGATIVE	=	-.04nS	ASYMMETRY POSITIVE	=	-.88nS

*** TRACK ANALYSIS ***

ID: AMBR3-1 04/01/97 12:48:17 TRACK # 6070 HEAD # 0

| Write Current: 10mA | Period: 15.02nS | Overwrite Frequency: 5.50MHz |

HI FREQ AMPLITUDE	=	170.uV	LO FREQ AMPLITUDE	=	268.uV
NEGATIVE MODULATION	=	-13.99%	POSITIVE MODULATION	=	14.39%
RESOLUTION	=	63.52%	PULSE WIDTH	=	20.78nS
			OVERWRITE	=	26.82db
ASYMMETRY NEGATIVE	=	.49nS	ASYMMETRY POSITIVE	=	-1.52nS

*** TRACK ANALYSIS ***

ID: AMBR3-1 04/01/97 12:54:13 TRACK # 6070 HEAD # 0

| Write Current: 10mA | Period: 15.02nS | Overwrite Frequency: 5.50MHz |

HI FREQ AMPLITUDE	=	177.uV	LO FREQ AMPLITUDE	=	277.uV
NEGATIVE MODULATION	=	-14.82%	POSITIVE MODULATION	=	16.69%
RESOLUTION	=	63.71%	PULSE WIDTH	=	20.81nS
			OVERWRITE	=	27.36db
ASYMMETRY NEGATIVE	=	.17nS	ASYMMETRY POSITIVE	=	-1.36nS

*** TRACK ANALYSIS ***

ID: AMBR3-1 04/01/97 12:54:30 TRACK # 6070 HEAD # 1

| Write Current: 10mA | Period: 15.02nS | Overwrite Frequency: 5.50MHz |

HI FREQ AMPLITUDE	=	201.uV	LO FREQ AMPLITUDE	=	291.uV
NEGATIVE MODULATION	=	-13.48%	POSITIVE MODULATION	=	14.64%
RESOLUTION	=	69.06%	PULSE WIDTH	=	21.19nS
			OVERWRITE	=	28.45db
ASYMMETRY NEGATIVE	=	.28nS	ASYMMETRY POSITIVE	=	-.81nS

*** TRACK ANALYSIS ***

ID: AMBR3-1 04/01/97 13:02:40 TRACK # 6070 HEAD # 0

| Write Current: 10mA | Period: 15.02nS | Overwrite Frequency: 5.50MHz |

HI FREQ AMPLITUDE	=	177.uV	LO FREQ AMPLITUDE	=	264.uV
NEGATIVE MODULATION	=	-15.86%	POSITIVE MODULATION	=	16.36%
RESOLUTION	=	67.02%	PULSE WIDTH	=	21.29nS
			OVERWRITE	=	27.44db
ASYMMETRY NEGATIVE	=	.50nS	ASYMMETRY POSITIVE	=	-.87nS

*** TRACK ANALYSIS ***

ID: AMBR3-1 04/01/97 13:02:54 TRACK # 6070 HEAD # 1

| Write Current: 10mA | Period: 15.02nS | Overwrite Frequency: 5.50MHz |

HI FREQ AMPLITUDE	=	198.uV	LO FREQ AMPLITUDE	=	290.uV
NEGATIVE MODULATION	=	-14.87%	POSITIVE MODULATION	=	14.19%
RESOLUTION	=	68.28%	PULSE WIDTH	=	20.47nS
			OVERWRITE	=	29.49db
ASYMMETRY NEGATIVE	=	.40nS	ASYMMETRY POSITIVE	=	-.86nS

*** TRACK ANALYSIS ***

ID: AMBR3-1 04/01/97 13:16:35 TRACK # 6070 HEAD # 1

| Write Current: 10mA | Period: 15.02nS | Overwrite Frequency: 5.50MHz |

HI FREQ AMPLITUDE	=	192.uV	LO FREQ AMPLITUDE	=	281.uV
NEGATIVE MODULATION	=	-12.55%	POSITIVE MODULATION	=	14.89%
RESOLUTION	=	68.20%	PULSE WIDTH	=	22.56nS
			OVERWRITE	=	28.62db
ASYMMETRY NEGATIVE	=	.73nS	ASYMMETRY POSITIVE	=	-1.03nS

*** TRACK ANALYSIS ***

ID: AMBR3-1 04/01/97 13:16:48 TRACK # 6070 HEAD # 0

| Write Current: 10mA | Period: 15.02nS | Overwrite Frequency: 5.50MHz |

HI FREQ AMPLITUDE = 178.uV
NEGATIVE MODULATION = -15.13%
RESOLUTION = 67.12%
ASYMMETRY NEGATIVE = .92nS

LO FREQ AMPLITUDE = 265.uV
POSITIVE MODULATION = 15.83%
PULSE WIDTH = 21.06nS
OVERWRITE = 27.28db
ASYMMETRY POSITIVE = -1.72nS

*** TRACK ANALYSIS ***

ID: AMBR3-1 04/01/97 13:30:42 TRACK # 6070 HEAD # 0

| Write Current: 10mA | Period: 15.02nS | Overwrite Frequency: 5.50MHz |

HI FREQ AMPLITUDE = 168.uV
NEGATIVE MODULATION = -14.59%
RESOLUTION = 62.07%
ASYMMETRY NEGATIVE = .93nS

LO FREQ AMPLITUDE = 270.uV
POSITIVE MODULATION = 16.10%
PULSE WIDTH = 21.38nS
OVERWRITE = 26.82db
ASYMMETRY POSITIVE = -1.02nS

*** TRACK ANALYSIS ***

ID: AMBR3-1 04/01/97 13:30:56 TRACK # 6070 HEAD # 1

| Write Current: 10mA | Period: 15.02nS | Overwrite Frequency: 5.50MHz |

HI FREQ AMPLITUDE = 195.uV
NEGATIVE MODULATION = -12.37%
RESOLUTION = 68.83%
ASYMMETRY NEGATIVE = .72nS

LO FREQ AMPLITUDE = 283.uV
POSITIVE MODULATION = 14.14%
PULSE WIDTH = 20.76nS
OVERWRITE = 29.74db
ASYMMETRY POSITIVE = -.29nS

MODE	TRACK	HEAD	PASS	CUR	SYNC	ZONE	WINDOW	PATTERN
NOT RDY	6070	1	65551.	10	167-190967	2	3.8	8000

*** DRIVE MENU ***

3...ID radius IN .84
5...Track Size uIN 156.00
7...Rotation Counterclockwise

4...Maximum track # 6075
6...Maximum head # 1
8...Rotational speed 5200

ESC...Return to F3 menu

Device information:

MAXTRK: 6075
 TYPE: 312MP, REV: 2.28, NAME: Guzik Technical En, LIB: 2.12
 DDH: 1.07 DLB: 2.09 INTRF: 1.30

01 SURF 2 TRAK 3 SYST 4 RST 5 SYNC 6 P-ON 7 DOS 8 RECL ODRV OFF9 ID:AMBR3-1

MODE	TRACK	HEAD	PASS	CUR	SYNC	ZONE	WINDOW	PATTERN
NOT RDY	6070	1	65551.	10	167-190967	2	3.8	8000

*** RWA PARAMETERS MENU ***

1...Bit Cell ns	7.51	2...OUTER Write Current	10
3...Flux Rvsl MFlux/s	66.60	4...INNER Write Current	10
5...Read/Mis. Thr.%	50.0	6...Track change cur.	2000
7...Extra Thresh %	25.0	8...Low Data Frq MFlx/s	11.20
9...Overwrite Filt.#	2 5.500MHZ	A...Enable Low Freq.	YES
B...Time constant uSec	12.0	C...External clock	DISABLED
D...Data Source	INTERNAL	E...Positional Multiplier	1.00000
F...Performance Filter	FILTER 1	G...MR Read Current mA	.00
H...Set External Diff.	LOW Freq	I...Set Soft Index RPM	5200
K...Extern. Clock MHz	15.0000		

*** UTILITIES

P...System calibration menu
 R...Display parameters
 T...Cleaning Cycle
 O...Overwrite Freq Menu

MENU ***

Q...Drive menu
 S...File management menu
 V...Scope Menu
 X...Multizone Menu
 U...Prog Filter Menu

01 SURF 2 TRAK 3 SYST 4 RST 5 SYNC 6 P-ON 7 DOS 8 RECL ODRV OFF9 ID:AMBR3-1

MODE	TRACK	HEAD	PASS	CUR	SYNC	ZONE	WINDOW	PATTERN
NOT RDY	6070	1	65551.	10	167-190967	2	3.8	8000

*** TRACK TEST MENU ***

1...Write then read		2...Read cycle	
E...Erase Negative	High	R...Erase Positive	High
3...Pattern	A000	8...Special Write MFlux/sec	5.00
4...Track Number	6070	9...Special Write	
5...Head Number	1	7...Write Isolated Pulses	
6...Bit Shift Analysis Menu		C...Write Low Frequency	
B...Step backward		F...Step forward	
T...Linear tests		N...Noise test	A...TAA and modulate
K...Display BSA plot		I...Clear BSA plot	J...Make BSA plot
M...BSA Table		G...Integrated Tests	
S...Offset test menu		P...Overwrite Test Menu	H...Pause in Test NO

*** EXTRA & NOISE TEST PARAMETERS ***

X...High Erase current	10	W...Erase direction	NEG
Y...Low Erase current	5	Z...Erase mode	High
Q...Low current range:	FROM 1 TO 21	O...Optimize low erase current	

01 SURF 2 TRAK 3 SYST 4 RST 5 SYNC 6 P-ON 7 DOS 8 RECL ODRV OFF9 ID:AMBR3-1

MODE	TRACK	HEAD	PASS	CUR	SYNC	ZONE	WINDOW	PATTERN
------	-------	------	------	-----	------	------	--------	---------

NOT RDY 6070 1 65551. 10 167-190967 2 3.8 8000

*** SURFACE TEST MENU ***
1...Test mode - Seek
2...Access mode - FROM 0 TO 6070 INC. 4
3...Head mode - Presnt head
4...Stop mode - 15 passes
5...BSA Window nS - 35.0
6...Pattern - AAAA
A...Error source - Comparator
B...Sync on error - OFF
C...Display status - ON
K...Skip repeated errors - OFF
N...Skip Range - 50 bytes
P...Error Position - Encoded

P...Print summary Q...Reset summary count H...Halt test
S...Start G...Continue
ESC...Return from test L...Popcorn Noise Menu

01 SURF 2 TRAK 3 SYST 4 RST 5 SYNC 6 P-ON 7 DOS 8 RECL 0DRV OFF9 ID:AMBR3-1

*** TRACK ANALYSIS ***

ID: AMBR3-2 04/01/97 13:44:35 TRACK # 6070 HEAD # 0

| Write Current: 10mA | Period: 15.02nS | Overwrite Frequency: 5.50MHz |

HI FREQ AMPLITUDE	=	179.uV	LO FREQ AMPLITUDE	=	263.uV
NEGATIVE MODULATION	=	-14.62%	POSITIVE MODULATION	=	14.28%
RESOLUTION	=	68.10%	PULSE WIDTH	=	19.77nS
			OVERWRITE	=	28.67db
ASYMMETRY NEGATIVE	=	1.69nS	ASYMMETRY POSITIVE	=	-.24nS

*** TRACK ANALYSIS ***

ID: AMBR3-2 04/01/97 13:44:57 TRACK # 6070 HEAD # 1

| Write Current: 10mA | Period: 15.02nS | Overwrite Frequency: 5.50MHz |

HI FREQ AMPLITUDE	=	189.uV	LO FREQ AMPLITUDE	=	288.uV
NEGATIVE MODULATION	=	-12.41%	POSITIVE MODULATION	=	13.79%
RESOLUTION	=	65.50%	PULSE WIDTH	=	21.23nS
			OVERWRITE	=	27.35db
ASYMMETRY NEGATIVE	=	1.37nS	ASYMMETRY POSITIVE	=	.07nS

*** TRACK ANALYSIS ***

ID: AMBR3-2 04/01/97 13:48:07 TRACK # 6070 HEAD # 1

| Write Current: 10mA | Period: 15.02nS | Overwrite Frequency: 5.50MHz |

HI FREQ AMPLITUDE	=	193.uV	LO FREQ AMPLITUDE	=	297.uV
NEGATIVE MODULATION	=	-12.65%	POSITIVE MODULATION	=	12.74%
RESOLUTION	=	64.92%	PULSE WIDTH	=	21.44nS
			OVERWRITE	=	27.91db
ASYMMETRY NEGATIVE	=	.71nS	ASYMMETRY POSITIVE	=	-.98nS

*** TRACK ANALYSIS ***

ID: AMBR3-2 04/01/97 13:48:18 TRACK # 6070 HEAD # 0

| Write Current: 10mA | Period: 15.02nS | Overwrite Frequency: 5.50MHz |

HI FREQ AMPLITUDE	=	187.uV	LO FREQ AMPLITUDE	=	261.uV
NEGATIVE MODULATION	=	-13.04%	POSITIVE MODULATION	=	13.95%
RESOLUTION	=	71.71%	PULSE WIDTH	=	20.88nS
			OVERWRITE	=	26.25db
ASYMMETRY NEGATIVE	=	1.00nS	ASYMMETRY POSITIVE	=	.00nS

*** TRACK ANALYSIS ***

ID: AMBR3-2 04/01/97 14:00:31 TRACK # 6070 HEAD # 0

| Write Current: 10mA | Period: 15.02nS | Overwrite Frequency: 5.50MHz |

HI FREQ AMPLITUDE	=	184.uV	LO FREQ AMPLITUDE	=	266.uV
NEGATIVE MODULATION	=	-13.42%	POSITIVE MODULATION	=	15.35%
RESOLUTION	=	69.00%	PULSE WIDTH	=	20.34nS
			OVERWRITE	=	28.90db
ASYMMETRY NEGATIVE	=	.86nS	ASYMMETRY POSITIVE	=	-.53nS

*** TRACK ANALYSIS ***

ID: AMBR3-2 04/01/97 14:00:46 TRACK # 6070 HEAD # 1

| Write Current: 10mA | Period: 15.02nS | Overwrite Frequency: 5.50MHz |

HI FREQ AMPLITUDE	=	191.uV	LO FREQ AMPLITUDE	=	288.uV
NEGATIVE MODULATION	=	-13.02%	POSITIVE MODULATION	=	12.84%
RESOLUTION	=	66.41%	PULSE WIDTH	=	21.25nS
			OVERWRITE	=	26.96db
ASYMMETRY NEGATIVE	=	.38nS	ASYMMETRY POSITIVE	=	-1.23nS

*** TRACK ANALYSIS ***

ID: AMBR3-2 04/01/97 14:15:16 TRACK # 6070 HEAD # 1

| Write Current: 10mA | Period: 15.02nS | Overwrite Frequency: 5.50MHz |

HI FREQ AMPLITUDE	=	192.uV	LO FREQ AMPLITUDE	=	283.uV
NEGATIVE MODULATION	=	-12.37%	POSITIVE MODULATION	=	13.71%
RESOLUTION	=	67.71%	PULSE WIDTH	=	21.07nS
			OVERWRITE	=	28.28db
ASYMMETRY NEGATIVE	=	1.10nS	ASYMMETRY POSITIVE	=	-.87nS

*** TRACK ANALYSIS ***

ID: AMBR3-2 04/01/97 14:15:31 TRACK # 6070 HEAD # 0

| Write Current: 10mA | Period: 15.02nS | Overwrite Frequency: 5.50MHz |

HI FREQ AMPLITUDE	=	187.uV	LO FREQ AMPLITUDE	=	265.uV
NEGATIVE MODULATION	=	-13.04%	POSITIVE MODULATION	=	15.35%
RESOLUTION	=	70.69%	PULSE WIDTH	=	20.28nS
			OVERWRITE	=	29.17db
ASYMMETRY NEGATIVE	=	1.26nS	ASYMMETRY POSITIVE	=	-.46nS

*** TRACK ANALYSIS ***

ID: AMBR3-2 04/01/97 14:30:01 TRACK # 6070 HEAD # 0

| Write Current: 10mA | Period: 15.02nS | Overwrite Frequency: 5.50MHz |

HI FREQ AMPLITUDE	=	188.uV	LO FREQ AMPLITUDE	=	257.uV
NEGATIVE MODULATION	=	-13.82%	POSITIVE MODULATION	=	13.06%
RESOLUTION	=	73.20%	PULSE WIDTH	=	19.69nS
			OVERWRITE	=	28.27db
ASYMMETRY NEGATIVE	=	1.11nS	ASYMMETRY POSITIVE	=	-.45nS

*** TRACK ANALYSIS ***

ID: AMBR3-2 04/01/97 14:30:13 TRACK # 6070 HEAD # 1

| Write Current: 10mA | Period: 15.02nS | Overwrite Frequency: 5.50MHz |

HI FREQ AMPLITUDE	=	190.uV	LO FREQ AMPLITUDE	=	280.uV
NEGATIVE MODULATION	=	-12.96%	POSITIVE MODULATION	=	13.87%
RESOLUTION	=	67.93%	PULSE WIDTH	=	21.64nS
			OVERWRITE	=	28.10db
ASYMMETRY NEGATIVE	=	.76nS	ASYMMETRY POSITIVE	=	-.81nS

*** TRACK ANALYSIS ***

ID: AMBR24-1 04/01/97 14:49:40 TRACK # 6070 HEAD # 0

| Write Current: 10mA | Period: 15.02nS | Overwrite Frequency: 5.50MHz |

HI FREQ AMPLITUDE	=	173.uV	LO FREQ AMPLITUDE	=	278.uV
NEGATIVE MODULATION	=	-18.16%	POSITIVE MODULATION	=	23.51%
RESOLUTION	=	62.33%	PULSE WIDTH	=	21.64nS
			OVERWRITE	=	24.60db
ASYMMETRY NEGATIVE	=	1.29nS	ASYMMETRY POSITIVE	=	-.79nS

*** TRACK ANALYSIS ***

ID: AMBR24-1 04/01/97 14:50:00 TRACK # 6070 HEAD # 1

| Write Current: 10mA | Period: 15.02nS | Overwrite Frequency: 5.50MHz |

HI FREQ AMPLITUDE = 216.uV
NEGATIVE MODULATION = -19.38%
RESOLUTION = 68.37%
ASYMMETRY NEGATIVE = .71nS

LO FREQ AMPLITUDE = 316.uV
POSITIVE MODULATION = 21.01%
PULSE WIDTH = 20.67nS
OVERWRITE = 28.12db
ASYMMETRY POSITIVE = -.65nS

*** TRACK ANALYSIS ***

ID: AMBR24-1 04/01/97 14:53:12 TRACK # 6070 HEAD # 1

| Write Current: 10mA | Period: 15.02nS | Overwrite Frequency: 5.50MHz |

HI FREQ AMPLITUDE = 221.uV
NEGATIVE MODULATION = -16.87%
RESOLUTION = 69.04%
ASYMMETRY NEGATIVE = 1.03nS

LO FREQ AMPLITUDE = 320.uV
POSITIVE MODULATION = 21.72%
PULSE WIDTH = 21.56nS
OVERWRITE = 27.70db
ASYMMETRY POSITIVE = -.84nS

*** TRACK ANALYSIS ***

ID: AMBR24-1 04/01/97 14:53:26 TRACK # 6070 HEAD # 0

| Write Current: 10mA | Period: 15.02nS | Overwrite Frequency: 5.50MHz |

HI FREQ AMPLITUDE = 175.uV
NEGATIVE MODULATION = -19.10%
RESOLUTION = 61.27%
ASYMMETRY NEGATIVE = 1.61nS

LO FREQ AMPLITUDE = 286.uV
POSITIVE MODULATION = 21.92%
PULSE WIDTH = 21.61nS
OVERWRITE = 25.31db
ASYMMETRY POSITIVE = -.59nS

*** TRACK ANALYSIS ***

ID: AMBR24-1 04/01/97 15:05:29 TRACK # 6070 HEAD # 0

| Write Current: 10mA | Period: 15.02nS | Overwrite Frequency: 5.50MHz |

HI FREQ AMPLITUDE = 175.uV
NEGATIVE MODULATION = -18.79%
RESOLUTION = 61.37%
ASYMMETRY NEGATIVE = 1.21nS

LO FREQ AMPLITUDE = 285.uV
POSITIVE MODULATION = 24.55%
PULSE WIDTH = 21.71nS
OVERWRITE = 24.44db
ASYMMETRY POSITIVE = -.98nS

*** TRACK ANALYSIS ***

ID: AMBR24-1 04/01/97 15:05:43 TRACK # 6070 HEAD # 1

| Write Current: 10mA | Period: 15.02nS | Overwrite Frequency: 5.50MHz |

HI FREQ AMPLITUDE = 214.uV
NEGATIVE MODULATION = -18.93%
RESOLUTION = 67.26%
ASYMMETRY NEGATIVE = .76nS

LO FREQ AMPLITUDE = 318.uV
POSITIVE MODULATION = 21.30%
PULSE WIDTH = 21.19nS
OVERWRITE = 28.80db
ASYMMETRY POSITIVE = -.49nS

*** TRACK ANALYSIS ***

ID: AMBR24-1 04/01/97 15:20:00 TRACK # 6070 HEAD # 1

| Write Current: 10mA | Period: 15.02nS | Overwrite Frequency: 5.50MHz |

HI FREQ AMPLITUDE = 206.uV
NEGATIVE MODULATION = -17.73%
RESOLUTION = 64.51%
ASYMMETRY NEGATIVE = .21nS

LO FREQ AMPLITUDE = 319.uV
POSITIVE MODULATION = 21.08%
PULSE WIDTH = 21.44nS
OVERWRITE = 28.19db
ASYMMETRY POSITIVE = -.78nS

*** TRACK ANALYSIS ***

ID: AMBR24-1 04/01/97 15:20:15 TRACK # 6070 HEAD # 0

| Write Current: 10mA | Period: 15.02nS | Overwrite Frequency: 5.50MHz |

HI FREQ AMPLITUDE = 178.uV
NEGATIVE MODULATION = -19.03%

LO FREQ AMPLITUDE = 286.uV
POSITIVE MODULATION = 24.18%

RESOLUTION	=	62.38%	PULSE WIDTH	=	21.59nS
ASYMMETRY NEGATIVE	=	1.21nS	OVERWRITE	=	24.16db
			ASYMMETRY POSITIVE	=	-.81nS

*** TRACK ANALYSIS ***

ID: AMBR24-1	04/01/97	15:34:55	TRACK # 6070	HEAD # 0
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| Write Current: 10mA | Period: 15.02nS | Overwrite Frequency: 5.50MHz |

HI FREQ AMPLITUDE	=	177.uV	LO FREQ AMPLITUDE	=	284.uV
NEGATIVE MODULATION	=	-19.17%	POSITIVE MODULATION	=	21.59%
RESOLUTION	=	62.56%	PULSE WIDTH	=	21.60nS
			OVERWRITE	=	24.50db
ASYMMETRY NEGATIVE	=	1.59nS	ASYMMETRY POSITIVE	=	-.57nS

*** TRACK ANALYSIS ***

ID: AMBR24-1	04/01/97	15:35:08	TRACK # 6070	HEAD # 1
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| Write Current: 10mA | Period: 15.02nS | Overwrite Frequency: 5.50MHz |

HI FREQ AMPLITUDE	=	220.uV	LO FREQ AMPLITUDE	=	312.uV
NEGATIVE MODULATION	=	-18.34%	POSITIVE MODULATION	=	21.40%
RESOLUTION	=	70.75%	PULSE WIDTH	=	20.76nS
			OVERWRITE	=	29.40db
ASYMMETRY NEGATIVE	=	.50nS	ASYMMETRY POSITIVE	=	-.73nS

*** TRACK ANALYSIS ***

ID: AMBR24-2	04/01/97	15:41:01	TRACK # 6070	HEAD # 1
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| Write Current: 10mA | Period: 15.02nS | Overwrite Frequency: 5.50MHz |

HI FREQ AMPLITUDE	=	190.uV	LO FREQ AMPLITUDE	=	274.uV
NEGATIVE MODULATION	=	-17.90%	POSITIVE MODULATION	=	20.19%
RESOLUTION	=	69.16%	PULSE WIDTH	=	21.29nS
			OVERWRITE	=	25.13db
ASYMMETRY NEGATIVE	=	1.38nS	ASYMMETRY POSITIVE	=	-.92nS

*** TRACK ANALYSIS ***

ID: AMBR24-2 04/01/97 15:41:17 TRACK # 6070 HEAD # 0

| Write Current: 10mA | Period: 15.02ns | Overwrite Frequency: 5.50MHz |

HI FREQ AMPLITUDE	=	188.uV	LO FREQ AMPLITUDE	=	278.uV
NEGATIVE MODULATION	=	-21.91%	POSITIVE MODULATION	=	22.34%
RESOLUTION	=	67.61%	PULSE WIDTH	=	21.57ns
			OVERWRITE	=	26.25db
ASYMMETRY NEGATIVE	=	1.30ns	ASYMMETRY POSITIVE	=	-1.80ns

*** TRACK ANALYSIS ***

ID: AMBR24-2 04/01/97 15:44:18 TRACK # 6070 HEAD # 0

| Write Current: 10mA | Period: 15.02ns | Overwrite Frequency: 5.50MHz |

HI FREQ AMPLITUDE	=	187.uV	LO FREQ AMPLITUDE	=	287.uV
NEGATIVE MODULATION	=	-19.60%	POSITIVE MODULATION	=	21.50%
RESOLUTION	=	65.06%	PULSE WIDTH	=	21.46ns
			OVERWRITE	=	26.10db
ASYMMETRY NEGATIVE	=	1.88ns	ASYMMETRY POSITIVE	=	-.80ns

*** TRACK ANALYSIS ***

ID: AMBR24-2 04/01/97 15:44:29 TRACK # 6070 HEAD # 1

| Write Current: 10mA | Period: 15.02ns | Overwrite Frequency: 5.50MHz |

HI FREQ AMPLITUDE	=	189.uV	LO FREQ AMPLITUDE	=	281.uV
NEGATIVE MODULATION	=	-19.29%	POSITIVE MODULATION	=	21.22%
RESOLUTION	=	67.30%	PULSE WIDTH	=	21.44ns
			OVERWRITE	=	26.25db
ASYMMETRY NEGATIVE	=	1.18ns	ASYMMETRY POSITIVE	=	-.55ns

*** TRACK ANALYSIS ***

ID: AMBR24-2 04/01/97 15:56:16 TRACK # 6070 HEAD # 1

| Write Current: 10mA | Period: 15.02nS | Overwrite Frequency: 5.50MHz |

HI FREQ AMPLITUDE	=	184.uV	LO FREQ AMPLITUDE	=	282.uV
NEGATIVE MODULATION	=	-18.69%	POSITIVE MODULATION	=	22.72%
RESOLUTION	=	65.20%	PULSE WIDTH	=	22.31nS
			OVERWRITE	=	25.40db
ASYMMETRY NEGATIVE	=	1.98nS	ASYMMETRY POSITIVE	=	-1.00nS

*** TRACK ANALYSIS ***

ID: AMBR24-2 04/01/97 15:56:30 TRACK # 6070 HEAD # 0

| Write Current: 10mA | Period: 15.02nS | Overwrite Frequency: 5.50MHz |

HI FREQ AMPLITUDE	=	193.uV	LO FREQ AMPLITUDE	=	281.uV
NEGATIVE MODULATION	=	-21.09%	POSITIVE MODULATION	=	21.11%
RESOLUTION	=	68.63%	PULSE WIDTH	=	21.00nS
			OVERWRITE	=	26.79db
ASYMMETRY NEGATIVE	=	.95nS	ASYMMETRY POSITIVE	=	-1.34nS

*** TRACK ANALYSIS ***

ID: AMBR24-2 04/01/97 16:08:31 TRACK # 6070 HEAD # 0

| Write Current: 10mA | Period: 15.02nS | Overwrite Frequency: 5.50MHz |

HI FREQ AMPLITUDE	=	186.uV	LO FREQ AMPLITUDE	=	282.uV
NEGATIVE MODULATION	=	-18.61%	POSITIVE MODULATION	=	20.50%
RESOLUTION	=	66.05%	PULSE WIDTH	=	21.49nS
			OVERWRITE	=	26.29db
ASYMMETRY NEGATIVE	=	1.43nS	ASYMMETRY POSITIVE	=	-1.03nS

*** TRACK ANALYSIS ***

ID: AMBR24-2 04/01/97 16:08:44 TRACK # 6070 HEAD # 1

| Write Current: 10mA | Period: 15.02nS | Overwrite Frequency: 5.50MHz |

HI FREQ AMPLITUDE	=	190.uV	LO FREQ AMPLITUDE	=	278.uV
NEGATIVE MODULATION	=	-18.64%	POSITIVE MODULATION	=	20.71%
RESOLUTION	=	68.46%	PULSE WIDTH	=	21.92nS
			OVERWRITE	=	25.51db
ASYMMETRY NEGATIVE	=	.74nS	ASYMMETRY POSITIVE	=	-.87nS

*** TRACK ANALYSIS ***

ID: AMBR24-2 04/01/97 16:26:32 TRACK # 6070 HEAD # 1

| Write Current: 10mA | Period: 15.02nS | Overwrite Frequency: 5.50MHz |

HI FREQ AMPLITUDE	=	186.uV	LO FREQ AMPLITUDE	=	280.uV
NEGATIVE MODULATION	=	-18.70%	POSITIVE MODULATION	=	24.89%
RESOLUTION	=	66.41%	PULSE WIDTH	=	21.51nS
			OVERWRITE	=	25.08db
ASYMMETRY NEGATIVE	=	1.22nS	ASYMMETRY POSITIVE	=	-.90nS

*** TRACK ANALYSIS ***

ID: AMBR24-2 04/01/97 16:26:47 TRACK # 6070 HEAD # 0

| Write Current: 10mA | Period: 15.02nS | Overwrite Frequency: 5.50MHz |

HI FREQ AMPLITUDE	=	199.uV	LO FREQ AMPLITUDE	=	285.uV
NEGATIVE MODULATION	=	-18.64%	POSITIVE MODULATION	=	22.47%
RESOLUTION	=	69.85%	PULSE WIDTH	=	21.53nS
			OVERWRITE	=	26.79db
ASYMMETRY NEGATIVE	=	1.37nS	ASYMMETRY POSITIVE	=	-1.23nS

*** TRACK ANALYSIS ***