

FLEXIBLE SUBSTRATE AND METHOD OF MANUFACTURE

FIELD

The present invention relates to a flexible substrate for flexible circuits and method of manufacturing such flexible substrates by laser skiving.

5 BACKGROUND

Flexible printed circuits (FPCs) are extensively used in electronic componetry including for example in hard disk drives. In hard disk drives FPCs are used for, among other things, connecting to the read/write heads. FPCs have been used in hard disk drives, to replace fine and manually routed wires, since magneto-resistive drive heads were introduced in the
10 1990s.

Flex-On-Suspension (FOS) circuits are one of the types of FPCs used for the electrical interconnection of the read/write head of hard disk drives. FOS circuits may be manufactured to consist of a 25 microns-thick substrate layer on top of which electro-deposited copper is plated using a semi-additive plating technology. The copper layer can
15 also be formed using other flex circuit manufacturing techniques such as subtractive technique where copper circuits are generated using conventional photolithography and copper etching technologies. The copper is cover-plated with a thin conductive protection layer such as gold to define electrical leads. These are then covered with an insulative cover layer.

20 In hard disk drive manufacturing, FOS circuits are attached to suspensions using an adhesive to form Flex Suspension Assemblies (FSA). An Air Bearing Slider (ABS), which carries the read/write head, is attached to the gimbal region of the FOS circuit. The entire assembly is called a Head Gimbal Assembly (HGA).

Hard disk storage capacity is ever increasing. One approach to increase the storage
25 capacity of a hard disk is to increase the areal density of magnetic recording of the hard disk. An increase in areal density increases the amount of data that can be stored in a given amount of "real estate" i.e. space on a hard disk platter. Higher areal densities require a

smaller form factor ABS to allow these to read from or write to the magnetic media. A small form factor ABS needs to fly at an extremely low flying height and at constant spacing above the rotating disk. Because of platter surface deviations, to ensure that a small form factor ABS can fly at a low flying height without head-crashing, it is important to have a compliant gimbal region of the FOS circuit. It is recognised that a compliant gimbal region may be achieved by providing an FOS circuit which can support an ABS in a flexible manner. Low stiffness support of the ABS will allow the ABS to fly at low heights and be more rapidly responsive to the surface deviations of a platter.

Low gimbal stiffness can be achieved by providing an FOS circuit manufactured using a thin substrate. Substrate thicknesses as thin as 6 microns are being used to achieve the low gimbal stiffness. However, manufacturers of FOS circuits, find it challenging to handle thin substrate FOS circuits. During reel-to-reel manufacturing of FOS circuits, manufacturing conditions need to be accurately controlled due to the fragile nature of thin substrate FOS circuits if a high yield is to be achieved.

One solution is to reduce the substrate thickness at selected areas. WO2004/023854 Yang et al describes the use of chemical etching of selected areas of a dielectric film. The film is then used as a substrate for flexible circuits.

US5910282: Grozdanovski et al describes cutting grooves or indentations into the surface of polyimide sheets to produce a stencil having surface mount land patterns for locating components on printed circuit boards. The cuts are made by directing pulsed laser beam against sheet surface in unison with pressurised gas, the depth of cut being determined by a combination of gas pressure, pulse duration, and power level.

SUMMARY

In broad terms in one aspect the invention comprises a method of using a laser to reduce the thickness at a zone of a substrate to be used in a flexible circuit, the method comprising the steps of traversing a laser beam from said laser directed against a surface of the substrate over said zone of said substrate to skive the surface of said substrate.

Preferably the substrate is of a thickness in the range of 25 microns to 60 microns save for at least said zone.

Preferably the traversing reduces the thickness of said substrate at said zone to a thickness less than 25 microns.

- 5 Preferably the zone extends to and between at least two edges of said substrate to define a zone of weakness which is intermediate of regions of said substrate which are not skived.

Preferably the flexible circuit is a flex-on-suspension circuit for use in a hard disk drive to provide electrical interconnection for an air bearing slider supported at a gimbal region of and by flex-on-suspension circuit, said zone defined at said gimbal region.

- 10 Preferably the substrate is selected from the group consisting of polyimide, poly(ethylene terephthalate), poly(ethylenenaphthalate), polycarbonate, polyetherimide and polyetheretherketone.

Preferably the substrate is a polyimide substrate.

- 15 In broad terms in another aspect the present invention includes a flexible substrate for a flexible circuit comprising a substrate having a thickness in the range of 25 microns to about 60 microns including at least one zone where the thickness of said substrate is reduced to less than 25 microns.

- 20 Preferably the zone or zones extends across said substrate to define at least two discrete regions of said substrate each of said discrete region having a thickness in the range of range of 25 microns to 60 microns.

Preferably the flexible circuit is a flex-on-suspension circuit for use in a hard disk drive to provide electrical interconnection for an air bearing slider supported at a gimbal region of a flex-on-suspension circuit, said zone defined at said gimbal region.

- 25 Preferably the substrate is selected from the group consisting of polyimide, poly(ethylene terephthalate), poly(ethylenenaphthalate), polycarbonate, polyetherimide and polyetheretherketone.

Preferably the substrate is a polyimide substrate.

In broad terms another aspect of the present invention includes a flexible circuit comprising a substrate, electrical leads formed on one major surface of said substrate, and an insulative layer covering the electrical leads to protect the electrical leads, wherein said substrate is of
5 a thickness in the range of 25 microns to 60 microns save for at least one zone at the other major surface of said substrate, where the thickness of said substrate is reduced to less than 25 microns.

Preferably the substrate is selected from the group consisting of polyimide, poly(ethylene terephthalate), poly(ethylenenaphthalate), polycarbonate, polyetherimide and
10 polyetheretherketone.

Preferably the substrate is a polyimide substrate.

In broad terms the present invention may also comprise a hard disk drive containing a flexible circuit as herein before described.

BRIEF DESCRIPTION OF DRAWINGS

15 The invention will be further described by way of example only and without intending to be limiting with reference to the following drawings, wherein:

Figure 1 is a perspective view of a Head Gimbal Assembly,

Figure 2 is an exploded view of the components included in the Head Gimbal Assembly of Figure 1,

20 **Figure 3** is a perspective view of an exemplary embodiment of a gimbal region of the Flex-On-Suspension circuit of the assembly of Figure 1,

Figure 4 is a perspective view of the gimbal region of Figure 1 showing the reverse side to that side shown on Figure 3,

Figure 5 is a perspective view of an alternatively configured gimbal region;

Figure 6 is a schematic view exemplary of a reel-to-reel process that may be utilised for manufacturing of the Flex-On-Suspension circuit of the present invention,

Figure 7 is a plan view of a frame incorporating multiple Flex-On-Suspension circuits which may utilised in reel-to-reel processing,

5 **Figure 8** is a perspective view of a hard disk drive, and

Figure 9 is a sectional view through section A-A of Figure 2

DETAILED DESCRIPTION

With reference to the drawings, examples of the invention will now be described in relation to Flex-on-Suspension (FOS) circuits to provide such with low gimbal stiffness. A method
10 of manufacture of FOS circuits using laser skiving to selectively thin a substrate at predetermined zones of the FOS circuits is also described.

FOS circuits may be used for interconnection purposes within a hard disk drive 1 as shown in Figure 8. A FOS circuit 2 is shown with reference to Figures 1 and 2. Figure 9 shows, in cross-section through section AA of Figure 2, the layered construction of an FOS circuit
15 2. The FOS circuit 2 may include a substrate 3 of a polyimide material. The polyimide substrate 3 may generally be of a thickness of approximately 25 microns. Polyimide is a commonly used material in electronic circuits and is known for its high temperature resistance.

Onto a face of the polyimide substrate 3 there is electro-deposited a number of copper leads
20 4 using, for example, semi-additive plating technology. The copper leads 4 may then be cover-plated with a thin conductive protection layer (not shown) such as gold, before the leads 4 are covered by an insulative cover layer 5.

The FOS circuit 2 includes a gimbal region 6, which holds an ABS 7. The FOS circuit 2 is attached to a suspension 8 to define a Flex Suspension Assembly 9. The suspension 8 is
25 normally made from stainless steel but the material of the suspension is not material to the present invention. With the ABS engaged at the gimbal region 6, the entire assembly defines a HGA 10.

With reference to Figures 3, 4 and 5, the gimbal region 6 of the FOS circuit 2, includes an ABS bonding area 11 at which the ABS (not shown in these figures) engages with the FOS circuit 2 and makes electrical connection with the terminals 12 of the copper leads 4.

Figures 3 and 5 illustrate the gimbal region 6 of the FOS circuit 2, with the substrate 3 facing upwards. Figure 4 shows the gimbal region 6 with the cover layer 5 facing upwards.

In order to support the ABS 7 in a flexible manner from the FOS circuit 2, the polyimide substrate 3 includes a zone or zones 13 of reduced thickness at the gimbal region 6. The zone or zones 13 of reduced thickness, reduces the stiffness of the gimbal region 6 thereby resulting in a more flexibly mounted ABS 7. A more flexibly mounted ABS 7 will allow the ABS 7 to be more responsive to surface deviations of a hard disk platter as it flies over the surface of the hard disk platter.

The reduction in thickness at a zone or zones 13 of the gimbal region 6 is provided by a localised reduction in thickness of the polyimide substrate 3 and is achieved by laser skiving.

Laser skiving allows removal of some of the polyimide substrate 3 yet can be controlled so as not to remove the entire substrate 3 at the zone or zones 13. Removal of the entire thickness of the polyimide substrate 3 is undesirable as to do so would risk exposing the copper leads 4. Exposing the copper leads 4 may result in an electrical short to the stainless steel suspension structure 8. Entire removal of the polyimide layer may also cause copper lead breakages at those areas during fabrication or during subsequent handling.

The size, shape and depth of the zone or zones 13 of polyimide material to be skived, can be determined by predictive engineering, such that the finished circuits can achieve the required stiffness. Such predictive engineering may include finite element analysis techniques to determine a size, shape and depth of the zone or zones 13 to be skived, to achieve a support of the ABS 7 with appropriate flexibility.

The polyimide substrate or more correctly the dielectric film used in the manufacture of (FOS) circuits may be any suitable polyimide including, but not limited to, those available under the trade names; UPILEX from Ube Industries, Ltd., Tokyo, Japan; APICAL from

Kaneka High-Tech Materials, Inc., Pasadena, Texas (USA); and KAPTON, including KAPTON E, KAPTON EN, KAPTON H, and KAPTON V from DuPont High Performance Materials, Circleville, Ohio (USA). Other polymers such as poly(ethylene terephthalate) (PET), poly(ethylenenaphthalate) (PEN) available under trade names of MYLAR and TEONEX respectively from DuPont Tiejin Films, Hopewell, Virginia (USA), polycarbonate and polyetherimide (PEI) available under trade name of LEXAN and ULTEM respectively from General Electric Plastics, Pittsfield, Massachusetts (USA), and polyetheretherketone available under trade name PEEK from Victrex Polymer, Lancashire (UK), can be used.

Laser skiving of a FOS circuit 2 involves the projecting of a laser beam 20 onto the zone or zones 13 of the substrate 3 to be skived. This may involve the passing of a laser beam 20 in a predetermined pattern over the substrate 3 to thereby remove polyimide material from the substrate 3. Using multiple laser pulses can increase the depth of skiving and provide depth control. Known manufacturing technology such as computer numeric control positioning devices can be used to position and move the FOS circuit 2 relative to a laser beam. Laser machining rate, power, and exposure time will determine the depth and depth tolerance of the regions of the substrate 3 to be thinned. Laser machining rate, power, and exposure time can all be programmed into the machines. The laser may also be controlled to provide variable depth of skiving, over a given skived zone.

Type of laser	CO ₂	Excimer	Nd: YAG
Medium	Molecular gas	Molecular gas	Solid State
Working frequency (nm)	9400 or 10600	193 to 351	212 to 1064
Working principle	Photothermal	Photochemical	Photothermal
Heat affected zone (HAZ)	Significant	Negligible	Can be minimized
Presence of charring	Yes	Can be minimized	Can be minimized
Resolution	Low	Highest	High
Conventional cleaning	Necessary	Depend on application	Necessary

Table 1

Table 1 lists some of the more common lasers used in machining plastics along with factors that need to be considered in selecting a suitable laser. Laser micromachining of plastics involves two general principles being photothermal ablation and photochemical ablation.

Photothermal ablation, is a process using high-energy infrared photons to break the

molecular bonds through vibration. Photochemical ablation uses higher-energy UV photons to sever the chemical bonds found within the absorbing material in a “laser cold cutting” process. Using photochemical ablation, material is removed by breaking the chemical bonds until the material dissociates into its chemical components.

- 5 Though the solid state Nd:YAG laser listed in Table 1 has some thermal effects on the material, trials using a UV Diode Pumped Solid State (DPSS) laser have shown that there are minimal adverse thermal effects associated with the photothermal ablation process. When using the UV DPSS laser to skive polyimide to achieve the objective of selectively thinning the material, the area to be skived can be defined in the computer-aided-
- 10 manufacturing (CAM) module of the laser system. One such UV DPSS laser system is ESI's UV Laser μ via Drilling machine.

The thermal effects of Nd:YAG type lasers include charring and burning of the material machined, debris may also remain on the machined surface. In hard disk drive manufacturing, cleanliness requirements are strict. The laser skived FOS circuits can, if

15 necessary, be cleaned using a plasma cleaning process to ensure that the cleanliness requirements are met.

The Excimer type lasers use a photochemical rather than photothermal process. The use of photochemical process results in reduced thermal effects on the machined materials, as compared to Nd:YAG type lasers. Cleaning of the laser skived FOS circuits may not

20 therefore be necessary.

To enhance laser accuracy, if necessary, additional processing steps may be incorporated in the manufacture of a FOS circuit 2. For example, a metal mask 14 may be utilised to enhance edge accuracy of the skived zone or zones 13. A metal mask 14 with a precisely machined opening or openings 22 may be used to define the areas on an FOS circuit 2

25 where the laser beam 20 is to skive. Various rectangular beam sizes are available with Excimer type lasers listed in Table 1. By using a beam size larger than the intended skived area and a metal mask 14, multiple areas can be skived concurrently, thus increasing processing efficiency. However, as mentioned, the laser machines may be precisely programmed or controlled to skive the required zones with the desired accuracy.

Mass fabrication of FOS circuits 2 may be achieved. With reference to Figure 6 there is shown a schematic diagram of a reel-to-reel manufacturing setup to manufacture a plurality of FOS circuits 2. Figure 6 illustrates roll stock frames 16 of FOS circuits 2. Each frame 17 carries a plurality of FOS circuits 2. With reference to Figure 7 there is shown such a frame 17, carrying an array of FOS circuits 2, juxtaposed next to each other and extending across the width of the frame. The string of frames 17 may be advanced over a machining terminal 18 where each frame can be subjected to laser skiving. A laser unit 19 may project a laser beam 20 onto the substrate disposed side of each frame 17 and skive the substrate to create the appropriately shaped reduced thickness zones 13. A mask 14 may be utilised to ensure accurate machining by the laser of the substrate 3. Skived frames 17 of FOS circuits 2, having passed the machining terminal 18, may then be appropriately handled, including their winding into a roll 21 or undergoing a cleaning process if necessary depending on the type of laser used in the machining process.

The zone or zones 13 may be very small. For example, a typical zone may be about a square with sides of 2 mm to 3 mm. But a zone may be of any shape at all. Laser skiving enables the selective removal of material at the gimbal region 6 while leaving the rest of the FOS circuit 2 untouched by the laser.

Laser skiving lends itself to high volume manufacturing such as in reel-to-reel manufacturing. Laser skiving can provide high yield manufacturing of the FOS circuits because the substrates 3 remain of a more robust thickness save for very localised thickness reduction(s). This allows the FOS circuits 2, to be handled with less care, while still providing the desired ABS support characteristics.

Laser skiving of polyimide materials may have application not just in FOS circuits but in other situations as well such as in integrated circuit packaging.

Skiving of a polyimide substrate may also be desired where a substrate needs to be bent. A polyimide substrate having reduced thickness at regions where bending is to occur, can enhance the ease at which the substrate can be bent.

The foregoing describes the invention including preferred forms thereof. Alterations and

modifications as will be obvious to those skilled in the art are intended to be incorporated in the scope hereof as defined by the accompanying claims.

CLAIMS

1. A method of reducing the thickness at a zone of a substrate for a flexible circuit using a laser, the method comprising the step of:

traversing a laser beam from said laser directed against a surface of the substrate over said zone of said substrate to skive the surface of said substrate.

2. A method as claimed in claim 1 wherein the substrate is of a thickness in the range of 25 microns to 60 microns save for at least said zone.

3. A method as claimed in claim 1 or 2 wherein the traversing is of a path and at a speed and the laser beam is of an intensity, to reduce the thickness of said substrate at said zone to a thickness less than 25 microns.

4. A method as claimed in any one of claims 1 to 3 wherein said zone extends to and between at least two edges of said substrate to define a zone of weakness which is intermediate of regions of said substrate which are not skived.

5. A method as claimed in any one of claims 1 to 4 wherein said flexible circuit is a flex-on-suspension circuit for use in a hard disk drive to provide electrical interconnection for an air bearing slider supported at a gimbal region of a flex-on-suspension circuit, said zone defined at said gimbal region.

6. A method as claimed in any one of claims 1 to 5 wherein said substrate is selected from the group consisting of polyimide, poly(ethylene terephthalate), poly(ethylenenaphthalate), polycarbonate, polyetherimide and polyetheretherketone.

7. A method as claimed in any one of claims 1 to 5 wherein said substrate is a polyimide substrate.

8. A flexible substrate for a flexible circuit comprising:

a substrate having a thickness in the range of 25 microns to 60 microns including at least one zone where the thickness of said substrate is reduced to less than 25 microns.

9. A flexible substrate as claimed in claim 6 wherein said zone or zones extends across said substrate to define at least two discrete regions of said substrate each said discrete region being of said thickness in the range of range of 25 microns to 60 microns to thereby increase the flexibility of said substrate.
- 5 10. A flexible substrate as claimed in claim 6 or 7 wherein said flexible circuit is a flex-on-suspension circuit for use in a hard disk drive to provide electrical interconnection for an air bearing slider supported at a gimbal region of and by flex-on-suspension circuit, said zone defined at said gimbal region.
- 10 11. A flexible substrate as claimed in any one of claims 8 to 10 wherein said substrate is selected from the group consisting of polyimide, poly(ethylene terephthalate), poly(ethylenenaphthalate), polycarbonate, polyetherimide and polyetheretherketone.
12. A flexible substrate as claimed in any one of claims 8 to 10 wherein said substrate is a polyimide substrate.
- 15 13. A flexible circuit comprising:
a substrate,
electrical leads formed on one major surface of said substrate, and
an insulative layer covering the electrical leads to protect the electrical leads,
20 wherein said substrate is of a thickness in the range of 25 microns to 60 microns save for at least one zone at the other major surface of said substrate, where the thickness of said substrate is reduced to less than 25 microns.
- 25 14. A flexible circuit as claimed in claim 9 wherein said zone or zones extends across said substrate to define at least two discrete regions of said substrate each said discrete region being of said thickness in the range of range of 25 microns to 60 microns to thereby increase the flexibility of said substrate.
15. A flexible circuit as claimed in claim 9 or 10 wherein said flexible circuit is a flex-on-suspension circuit for use in a head gimbal assembly of a hard disk drive

to provide electrical interconnection for an air bearing slider supported at a gimbal region of and by flex-on-suspension circuit, said zone defined at said gimbal region.

- 5 16. A flexible circuit as claimed in any one of claims 13 to 15 wherein said substrate is selected from the group consisting of polyimide, poly(ethylene terephthalate), poly(ethylenenaphthalate), polycarbonate, polyetherimide and polyetheretherketone.
17. A flexible circuit as claimed in any one of claims 13 to 15 wherein said substrate is a polyimide substrate.
- 10 18. A hard disk drive containing a flexible circuit as claimed in any one of claims 13 to 17.