

A METHOD OF TEXTURING THE SURFACE OF A BRITTLE MATERIAL

DESCRIPTION

This invention relates generally to the texturing of a surface of a brittle material, such as a glass substrate for a magnetic data storage disk substrate, and more specifically to such methods which irradiate the surface in order to texture it.

Recent magnetic disk drive designs employ a commonly denominated Contact Start-Stop (CSS) system in which the magnetic head contacts the magnetic disk surface when the disk is stationary. When the disk starts to rotate, the magnetic head slides along the surface, eventually flying fully lifted from the surface because of laminar air flow at the disk surface.

A smooth, specular recording surface is preferred in the art to permit the magnetic head to ride as closely as possible to the disk surface. Creation of a "textured" region on the metallic disk surface for magnetic head contact during CSS is used in the art to overcome the excessive contact stiction and friction developed during startup and stopping of disk rotation. The magnetic head is moved to the "CSS region" at the appropriate times by the drive controller. The specular smoothness of the remainder of the disk surface is retained to permit high-density magnetic data recording.

Several useful techniques for texturing metal disk surfaces have been proposed. For instance, the use of repetitive laser pulses to create reproducible pits on a metal surface is known for application to sheet-metal stamping surfaces, liquid transfer surfaces and metal data storage disk surfaces, as discussed in the "Procedure Employing a diode-pumped laser for controllably texturing a disk surface", US application 150525 (SA9-93-005), filed 10 November 1993 by the applicant of the present application, and a copy of which is filed herewith. Unfortunately, such techniques are not generally useful for texturing of brittle nonmetallic disk substrate surfaces such as the glass substrate known in the art for certain data storage disk applications. A brittle nonmetallic surface, especially a glass surface, is expected to crack or deform excessively during the grinding or laser texturing techniques known in the art for metal disk substrates. Accordingly, chemical

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surface texturing techniques and other patterned deposition techniques are preferred in the art for brittle surfaces such as ferrite or glass.

For instance, in U.S. patents 5,079,657 and 5,162,073, Michael I. Aronoff et al. disclose a selective chemical etching technique for texturing the flying surface of a magnetic head. Aronoff et al. teach a stiction-reducing approach that avoids the necessity of texturing a CSS region on the recording disk but is disadvantageously limited to specific head surface materials.

In U.S. patent 4,985,301, Toshinori Morizane et al. disclose a method for manufacturing a glass base plate for a recording disk that includes subjecting the base plate to chemical etching treatments that provide different rates of etching between a crystallized material and an amorphous material. Morizane et al. teach the use of their method for creating a textured CSS region in the base plate that is reproduced through a subsequently-deposited recording material layer. Other practitioners have suggested using expensive chemical vapor deposition (CVD) processes to create roughened zones on a glass disk surface before deposition of the magnetic recording film layer.

The use of laser pulses is known in printing to create many tiny pits in the surface of a brittle material such as tungsten carbide. For instance, U.S. patents 5,143,578 and 5,236,763, disclose a method for engraving a series of consecutive cells or pits in a solid surface such as the liquid transfer surface of a printing roller. This technique is recommended to overcome the surface hardness of the ceramic and metal carbide surfaces normally used in engraving applications but the patents neither consider nor suggest solutions to the particular problems of CSS region creation in brittle nonmetallic disk surfaces to overcome head stiction.

Others have considered the specific problem of using laser energy for reducing stiction in data recording disks having glass substrates. For instance, in Japanese patent 4-311814, Maeta Hiroshi discloses a technique for texturing the glass substrate without reducing surface durability by applying a laser pulse from the back of the translucent substrate to fracture and scatter small particles of glass at the front surface. The laser pulse induces thermal shock that effectively breaks up the front surface into fine grains that are then supposedly partially

annealed to the front surface, creating a roughened topography suitable for reducing stiction in the magnetic recording film layer that is later added to the front glass substrate surface. Hiroshi doesn't discuss how his method overcomes the problems resulting from uncontrolled surface damage.

In U.S. patents 5,062,021 and 5,108,781, Rajiv Ranjan et al. disclose a process for creating a series of closely-spaced pits in the metallic surface of a magnetic recording disk to reduce stiction. Ranjan et al. teach the use of a flashlamp-pumped neodymium-yttrium-aluminum-garnet (Nd:YAG) laser to create the necessary surface roughness. However, they neither consider nor suggest the application of their texturing method to glass disk substrates or other brittle nonmetallic surfaces, and indeed their method is generally known to be impractical for brittle nonmetallic materials.

Practitioners in the art generally avoid using laser pulses to create controlled changes to the topography of a brittle nonmetallic surface, expecting hair-line cracking or surface material damage. This damage, often at the microscopic level, is frequently observed after laser melting of any brittle nonmetallic material such as glass because of the rapid melting and resolidification caused by a short laser pulse. This rapid melting and resolidification usually causes excessive stress in the glass, which forces the surface to crack and break up.

Such laser pulses are herein said to create stress that exceeds a "thermal shock threshold" for the brittle nonmetallic surface material. Indeed, the above-cited Hiroshi patent relies on this thermal shock micro-fracturing phenomenon for the usefulness of the claimed invention. Laser pulse energies below this threshold are generally believed to be useless for altering the topography of brittle nonmetallic surfaces.

Accordingly, the invention provides a method of texturing the surface of a brittle material by irradiating the surface with radiant energy at a plurality of locations, and characterised in that said radiant energy has a fluence f_p at each location, wherein said fluence f_p is less than the thermal shock threshold for the brittle material.

Such a texturing technique provides the controllability and other advantages of the laser-texturing techniques known in the art for metal surfaces.

It is preferred that said radiant energy comprises a pulse of laser energy E_p having a duration t_p and a focussed spot having a maximum diametral dimension D_p , wherein E_p , t_p and D_p are selected to limit said fluence f_p to a value below said thermal shock threshold, whereby a bump is formed in said each target area, and said pulse duration t_p is in the interval $[10^{-9}, 10^{-1}]$ seconds and said maximum spot diametral dimension D_p is in the interval $[1, 500]$ micrometers. It is further preferred that said bump rises to a maximum height h_d above said brittle surface, said maximum bump height h_d being in the interval $[1, 1000]$ nanometers, and each bump has a maximum diametral dimension D_d ($< D_p$) and each location is separated from the nearest neighboring location by a spacing distance $D_s \geq D_d$.

In an alternative arrangement, each bump has a maximum diametral dimension D_d and each location is separated from the nearest neighboring location by a spacing distance D_s substantially less than said maximum diametral dimension D_d , whereby a plurality of said bumps merge with their neighboring bumps to form a substantially continuous ridge on said surface.

Typically said brittle material is glass and said laser energy pulse has a wavelength λ_p such that the optical penetration of said laser energy pulse into the glass surface is in the interval $[10^{-8}, 10^{-3}]$ meters, and said laser pulses are generated by a carbon dioxide (CO_2) laser, and said wavelength λ_p is in a spectral region which is strongly absorbed by the brittle glass surface.

The invention also provides a method for manufacturing a data recording disk using a glass plate with a brittle surface, said method comprising the steps of:

- polishing said glass surface to a predetermined smoothness;
- texturing said glass surface using the method of any preceding claim; and

- depositing over said glass surface a film of magnetic data recording material to create a data recording layer.

The invention further provides a magnetic recording disk having an outer surface for storing magnetically-readable data, said disk comprising:

- a layer of glass substrate material having a substantially planar substrate surface; and

- a magnetizable film layer deposited over said glass substrate surface having a substantially uniform thickness and substantially planar recording surface,

wherein said outer surface includes a plurality of bumps, each said bump having a maximum diametral dimension D_d and rising to a maximum height h_d above the planar recording surface.

The above approach exploits the unexpected discovery that high-reproducible bumps can be controllably made on a glass disk surface using single laser pulses of precisely-controlled energy fluence. Fluence control is required to exploit an unexpected comparatively narrow operating region just under the abrupt thermal-shock fluence threshold for the brittle nonmetallic material. Fluence control is accomplished using selected combinations of laser wavelength, pulsewidth and repetition rate combined with proper bump spacing to avoid overstressing of the laser irradiated region. The narrow operating fluence region is bounded above by the thermal shock threshold and below by the melting or softening point of the material.

Thus a method can be adopted for texturing a brittle surface composed essentially of a brittle materials having a thermal shock threshold fluence level above which said brittle material is fractured, said method comprising a step of:

- concentrating radiant energy selectively on a plurality of spaced-apart locations over a treatment area of said brittle surface to alter the topography of said brittle surface in a target area at each said spaced-apart location, said radiant energy having a fluence f_p at said each spaced-apart location, said fluence f_p being less than said thermal shock threshold for said brittle material.

Many microscopic bumps may be created in a desired CSS region of a glass, ceramic or other brittle nonmetallic substrate surface to improve stiction, wear, friction, or coatability of such surfaces or to prepare the surface as a "stamping surface" mold for reproducing a negative impression. Highly-reproducible microscopic bumps can be controllably

created on a selected region of a surface using a pulsed laser, without damage to the brittle nonmetallic surface caused by micro-cracking because of laser pulse heating. The laser pulse fluence is tightly controlled within a proper region just under the thermal-shock fluence threshold at which occurs such hair-line cracking of the glass surface and material ejection. This feature arises from the completely unexpected discovery that there is an abrupt transitional energy fluence threshold (the "thermal shock threshold") below which the laser pulse energy fluence either has no effect or merely creates a bump without damage. For a glass disk with compressive surface stress, such a bump unexpectedly protrudes almost entirely above the nominal surface, which is remarkably useful for reducing stiction in data storage disks.

An embodiment of the invention will now be described in detail by way of example only with reference to the following drawings:

Fig. 1 is a functional schematic diagram of an exemplary apparatus for texturing a glass or other brittle surface in accordance with the method of the invention;

Figs. 2A-2C show a typical surface bump array and bump profile obtained using the method of this invention;

Figs. 3A-3D show the surface texture of a glass substrate for four different fluence levels, two of which cause micro-cracking of the surface;

Fig. 4 is a plan view of a rotatable magnetic recording disk and magnetic head, including a Contact Start-Stop (CSS) region for contact between the magnetic head and recording disk;

Fig. 5 is an enlarged sectional view of the magnetic disk of Fig. 4; and

Fig. 6 is a functional block diagram of a Direct Access Storage Device (DASD) employing an embodiment of the textured recording disk.

The present invention arises from the unexpected discovery that highly-reproducible, microscopic bumps can be controllably, inexpensively and quickly made on a glass disk surface using single laser pulses of the proper wavelength, pulsewidth and repetition rate combined with proper movement of the disk surface. Fig. 1 shows a functional schematic diagram of an exemplary apparatus suitable for implementing the present invention. This disclosure is primarily concerned with the texturing of glass storage disk substrates for reduced stiction, although the apparatus of Fig. 1 may be employed for

creating a desired patterned area on glass, ceramic or other brittle nonmetallic substrate surfaces for purposes of reduced stiction, improved wear or improved coatability, or as a "stamping surface" for use in mass production of other surfaces imprinted with the negative of the stamping pattern. Thus, the present invention can be appreciated as having general applicability even though it was originally motivated by the need to texture glass disks for data-storage.

In Fig. 1, a pulsed laser 10 is chosen so that the optical penetration of the radiation incident on the glass disk substrate 12 is longer than 10 nanometers and shorter than one millimeter to produce effective "near-surface" heating of the glass substrate. The pulsewidth is chosen to be longer than one nanosecond and shorter than 100 milliseconds to provide efficient heating of the interaction volume without causing excessive thermal shock (below one nanosecond) or excessive volumetric heating through thermal-diffusion (above 100 milliseconds). The laser peak power and the focussed spot size on the two surfaces 14 and 16 of glass disk 12 are chosen for an "energy density" or "fluence" sufficient to provide gentle surface softening or melting over a short time period without causing the shattering and material ejection from surfaces 14-16 expected at higher fluence values.

Laser 10 is controlled by a pulsed radio-frequency (rf) excitation signal 18 to provide a pulse repetition rate that, when combined with proper translation and rotational movement of glass substrate 12, provides single laser-pulse action in a new target area on surfaces 14-16 each time the laser fires. This requirement is necessary because it provides a wider operating range of fluences below the "thermal shock threshold" at which surface cracking and material ejection occurs. Although this "spaced-apart" target area requirement is preferred, overlapping irradiation target spots may be used, but with a narrower acceptable operating range of fluences below the thermal-shock fluence threshold.

The operation of the apparatus in Fig. 1 is now described. Disk substrate 12 is rotated on a shaft 20 by means of a motor 22 and the entire motor-shaft assembly is translated radially by some useful translation means (not shown). In synchronism with disk rotation and translation, laser 10 is pulsed by signal 18 to provide the output pulses 24. Output pulses 24 can be split by deflection with a movable

mirror 26 to either an upper stationary mirror 28 or a lower stationary mirror 30. Pulses 24 travelling along the upper path bounce off mirror 28 through a ZnSe focussing lens 32 to a stationary mirror 34 and therefrom to upper surface 14 of glass substrate disk 12. Similarly, pulses 24 along the lower path bounce off mirror 30 through the ZnSe focussing lens 36 to mirror 38 and therefrom to lower surface 16 of disk 12. Thus, with proper mechanical control of mirror 26, both sides 14 and 16 may be textured simultaneously.

In Fig. 1, the texturing at surfaces 14-16 is controlled by the combination of pulse energy, spot size, pulse rate, pulse width, disk rotation rate and disk translation rate. In addition to these control elements, the laser wavelength is selected to obtain the near-surface heating effect discussed above. The energy fluence at surfaces 14-16 is precisely controlled in a manner exemplified by the above discussion in connection with Fig. 1. This requirement is important because of the unexpected discovery that there exists a rather abrupt energy fluence "thermal-shock threshold level" for many brittle nonmetallic surfaces including glass. Above this threshold, the glass surface is at least partially shattered and material can be ejected. In much of the energy fluence region below the thermal-shock fluence threshold, energies are insufficient to create any topographical alteration to the brittle nonmetallic surface. The present invention exploits the heretofore unknown and relatively narrow fluence region properly below the thermal-shock threshold to create useful surface textures in brittle nonmetallic materials.

Fig. 2A shows the texture on a glass surface resulting from an exemplary combination of process parameters to create a CSS zone on a glass recording disk substrate. The plurality of bumps in Fig. 2A exemplifies the texture produced, showing each bump separated from its neighboring bump by a desired separation distance D_s . Fig. 2B shows the Atomic Force Microscope (AFM) profile measured along the path crossing the single bump shown in Fig. 2C. The profile in Fig. 2B is seen to have a maximum diametral dimension D_d of substantially 60 micrometers (ie from 30 to 90 micrometers) and a maximum height h_d of substantially 100 nanometers above the surrounding substrate surface plane. The bumps are very smooth and ideally suited for reducing stiction in a CSS region of a data storage disk. Even with a protruding height h_d of 100 nanometers for the bumps, no cracks or shattering is observed on the

glass surface. Lower bump height, i.e. h_b approximately in the range from 3 to 40 nanometers, can be more desirable for CSS region texturing. These shorter bumps can be created by using lower laser fluences than those necessary for the 100 nanometer bumps. No cracking or shattering is produced during creation of such shorter bumps, either.

The following process parameters are herein disclosed as an example of an acceptable operating window providing energy fluence below the thermal-shock threshold for a glass surface:

- laser wavelength, $\lambda_p = 10.6$ micrometers;
- laser pulse width, $t_p = 60$ microseconds;
- laser pulse peak power, $P_p = 12$ watts;
- focussed target spot diameter, $D_p = 200$ micrometers;
- pulse repetition rate, $F_p = 1500$ Hertz;
- disk rotational speed, $\omega = 4\pi$ radians/second;
- disk translational speed, $v_t = 200$ micrometers/second; and
- nominal radial bump spacing, $r_s = 100$ micrometers.

It should be appreciated that although the target area spot size D_p is 200 micrometers, the bump size D_b is only 30 micrometers. This relationship illustrates the "threshold" characteristics of the laser texturing process that create a feature size much smaller than the radiated spot size. It is conjectured that the unexpected "fully-protruded" dimpling effect may result from a relaxation of surface stress caused by the laser-induced surface softening or by the laser-induced thermal expansion that "freezes-in" as the surface cools below the softening point, although this is not known for certain.

Bumps of height h_b from a few nanometers to as large as many micrometers can be produced by this technique. It has been demonstrated that larger bump heights can be produced through repetitive pulsing of the same target region spot without producing cracks, provided that the thermal shock threshold fluence level is not exceeded by any one pulse.

Fig. 3A-3D illustrate the effects of exceeding the thermal-shock fluence threshold in a glass surface and also demonstrate the abrupt upper limit of the acceptable fluence operating region. Each of the surfaces in Figs. 3A-3D were produced using the same operating parameters as are discussed above in connection with Fig. 2A, except for repetition rate ($F_p = 2,000$ Hz instead of 1,500 Hz) and for pulse

width t_p . Bump spacing in Figs. 3A-3D is less than in Fig. 2A because of the increased repetition rate F_p .

Fig. 3D shows the surface texture resulting from a pulse width $t_p = 60$ microseconds. Fig. 3C shows the surface texture produced by a 33% increase in t_p to 80 microseconds. The surface in Fig. 3C remains free of visible micro-cracks and debris. However, Fig. 3B shows extensive evidence of the micro-cracking that results with only an additional 12.5% increase in pulse width t_p to 90 microseconds. It is this unexpectedly abrupt thermal-shock fluence threshold characteristic of brittle nonmetallic surfaces that motivated the refined fluence control element of the texturing process described herein. Finally, Fig. 3A shows the extensive surface damage and material ejection known in the art for laser-textured brittle nonmetallic surfaces. Fig. 3A is created by a pulse width $t_p = 150$ microseconds, which is 250% of the value used for Fig. 3D.

Figs. 4 and 5 show a magnetic storage disk 40 having a specular outer surface 42 and a textured annular region 44 for use in Contact Start-Stop (CSS) cycling of the magnetic head 46. Magnetic head 46 is mounted on an arm 48, which is connected to means (not shown) for positioning head 46 in a generally radial direction with respect to rotating disk 40. In particular, head 46 is positioned over textured annular region 44 whenever the rotation of disk 40 is started or stopped.

Specular outer surface 42 of disk 40 (Fig. 5) may cover several layers of intervening materials. For instance, a glass substrate 12 may be formed and textured in accordance with the present invention before deposition of the subsequent magnetic recording layer 50 and protective layer 52. The topographical features of the textured surface of glass substrate 12 are reproduced at the surface of each subsequent layer deposited, thereby providing the desired texture in CSS region 44 on outer surface 42. Alternatively, any of the layers above glass substrate 12 may first be deposited and then textured in accordance with the present invention. Thus outer surface 26 effectively represents the surface of whichever of layers 12, 50 or 52 is modified topographically in accordance with the present invention. Ultimately, for data storage disk applications, the surface of protective layer 52 exhibits the

desired texture in the CSS region provided by textured annular region 44.

Fig. 6 shows a functional block diagram of a Direct Access Storage Device (DASD) 54 employing the textured disk 40 having the glass substrate 12. DASD 54 includes a control unit 56, which coordinates the operation of all elements with rotating disk 40. Control unit 56 provides a motor control signal 58 to a drive motor 60, which rotates disk 40 through a shaft 62. Control unit 56 also operates a head actuator 64 through a position control line 66. Actuator 64 is mechanically coupled through the two flexible members 68 and 70 to the two magnetic heads 72 and 74, respectively. Magnetic head 72 is disposed to read and write data on upper surface 42 of disk 40 and head 74 is similarly disposed to read and write data on the lower surface 76 of rotating disk 40. Heads 72 and 74 are coupled through a read/write channel 78 to control unit 56, whereby digital data is transferred to and from rotating disk 40.

CLAIMS

1. A method of texturing the surface (14) of a brittle material by irradiating the surface with radiant energy at a plurality of locations, and characterised in that said radiant energy has a fluence f_p at each location, wherein said fluence f_p is less than the thermal shock threshold for the brittle material.
2. The method of claim 1 wherein said radiant energy comprises a pulse of laser energy E_p having a duration t_p and a focussed spot having a maximum diametral dimension D_p , wherein E_p , t_p and D_p are selected to limit said fluence f_p to a value below said thermal shock threshold, whereby a bump is formed in said each target area.
3. The method of claim 2 wherein said pulse duration t_p is in the interval $[10^{-9}, 10^{-1}]$ seconds and said maximum spot diametral dimension D_p is in the interval $[1, 500]$ micrometers.
4. The method of claim 2, or 3, wherein said bump rises to a maximum height h_d above said brittle surface, said maximum bump height h_d being in the interval $[1, 1000]$ nanometers.
5. The method of claim 2, 3 or 4, wherein each bump has a maximum diametral dimension D_d and each location is separated from the nearest neighboring location by a spacing distance $D_s \geq D_d$.
6. The method of claim 2, 3 or 4 wherein each bump has a maximum diametral dimension D_d and each location is separated from the nearest neighboring location by a spacing distance D_s substantially less than said maximum diametral dimension D_d , whereby a plurality of said bumps merge with their neighboring bumps to form a substantially continuous ridge on said surface.
7. The method of any of claims 2 to 6 wherein said brittle material is glass and said laser energy pulse has a wavelength λ_p such that the optical penetration of said laser energy pulse into the glass surface is in the interval $[10^{-8}, 10^{-3}]$ meters.



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8. The method of claim 7 wherein said laser pulses are generated by a carbon dioxide (CO_2) laser, and said wavelength λ_p is in a spectral region which is strongly absorbed by the brittle glass surface.

9. A method for manufacturing a data recording disk using a glass plate (12) with a brittle surface, said method comprising the steps of:
polishing said glass surface to a predetermined smoothness;
texturing said glass surface using the method of any preceding claim; and

depositing over said glass surface a film of magnetic data recording material (50) to create a data recording layer.

10. A magnetic recording disk (40) having an outer surface for storing magnetically-readable data, said disk comprising:

a layer of glass substrate material (12) having a substantially planar substrate surface; and

a magnetizable film layer (50) deposited over said glass substrate surface having a substantially uniform thickness and substantially planar recording surface,

wherein said outer surface includes a plurality of bumps, each said bump having a maximum diametral dimension D_d and rising to a maximum height h_d above the planar recording surface.

11. The magnetic recording disk of claim 10 wherein said maximum diametral dimension $D_d < D_s$ is in the interval [1, 200] micrometers and said bump height h_d is in the interval [1, 1000] nanometers.

12. The magnetic recording disk of claim 10 or 11 wherein said plurality of bumps are separated from one another by a minimum separation distance $D_s > D_d$ in the interval [1, 500] micrometers.

13. The magnetic recording disk of claim 10 or 11, wherein each bump is separated from the nearest neighboring bump by a spacing distance D_s substantially less than said maximum diametral dimension D_d , whereby a plurality of said bumps merge with their neighboring bumps to form a substantially continuous ridge on said brittle surface.



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14. A direct access storage device for reading and storing data, including a magnetic recording disk according to any of claims 10 to 13, a magnetic head (46), and means (48) for supporting said head in a selected orientation and for generally radial controlled movement relative to said disk.

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