US006728196B2

(12) **United States Patent**
Edwards

(10) **Patent No.: US 6,728,196 B2**
(45) **Date of Patent: Apr. 27, 2004**

(54) **REVERSE OPTICAL MASTERING FOR DATA STORAGE DISKS**

(75) Inventor: **Jathan D. Edwards**, Afton, MN (US)

(73) Assignee: **Imation Corp.**, Oakdale, MN (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 241 days.

(21) Appl. No.: **09/850,252**

(22) Filed: **May 7, 2001**

(65) **Prior Publication Data**

US 2001/0016301 A1 Aug. 23, 2001

Related U.S. Application Data

(60) Division of application No. 09/730,246, filed on Dec. 5, 2000, which is a continuation-in-part of application No. 09/055,825, filed on Apr. 6, 1998, now abandoned.

(30) **Foreign Application Priority Data**

Apr. 2, 1999 (WO) PCT/US/07258

(51) **Int. Cl.**[7] **G11B 7/00**
(52) **U.S. Cl.** **369/275.4**; 369/277
(58) **Field of Search** 369/275.4, 277, 369/283, 284; 430/321; 101/28

(56) **References Cited**

U.S. PATENT DOCUMENTS

4,150,398	A	4/1979	Kojima et al.
4,304,806	A	12/1981	Anderson et al.
4,308,337	A	12/1981	Roach et al.
4,374,077	A	2/1983	Kerfeld
4,519,065	A	5/1985	Lewis et al.
4,619,804	A	10/1986	Leonard et al.
4,650,735	A	3/1987	De Last
5,096,563	A	3/1992	Yoshizawa et al.
5,149,607	A	9/1992	De Graaf et al.
5,516,469	A	5/1996	Santoh et al.
5,576,918	A	11/1996	Bar-Gadda et al.
5,626,941	A	5/1997	Ouano

(List continued on next page.)

FOREIGN PATENT DOCUMENTS

DE	41 40 712	A1	10/1992
EP	0 444 367	A1	9/1991

(List continued on next page.)

OTHER PUBLICATIONS

F. Dill et al., "Characterization of Positive Photoresist," IEEE Transactions on Electron Devices, vol. ED–22 , No. 7, Jul. 1975, 445–452.

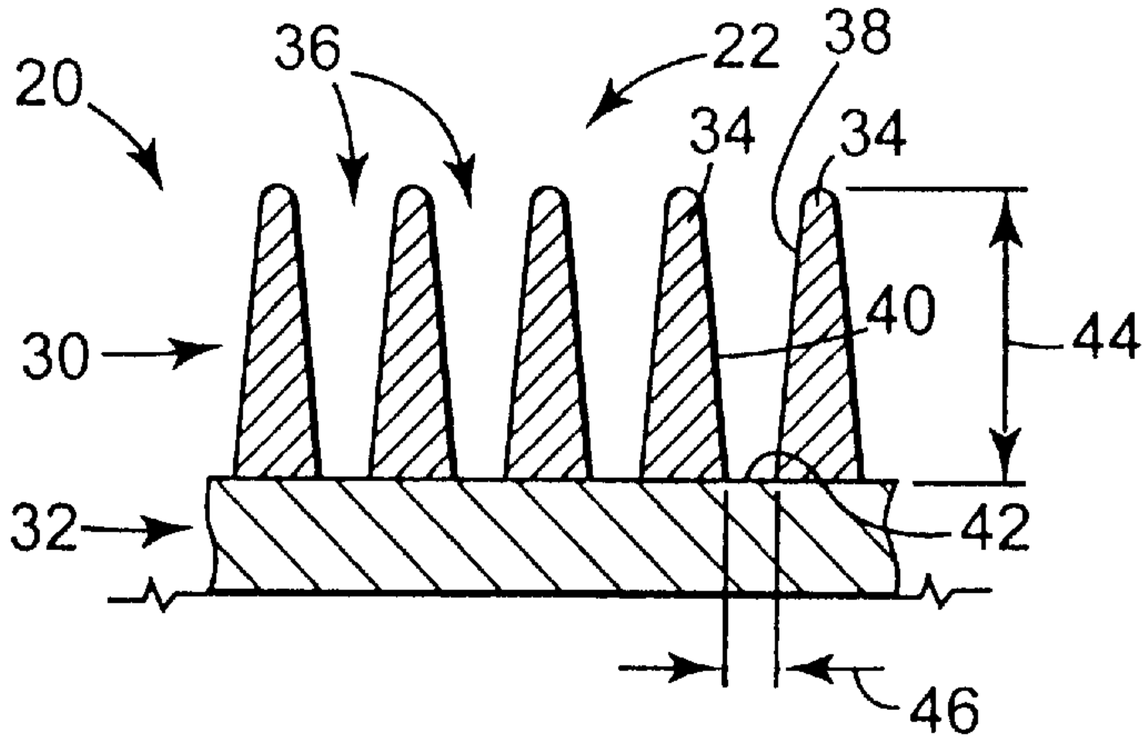
(List continued on next page.)

Primary Examiner—Paul W. Huber
(74) *Attorney, Agent, or Firm*—Eric D. Levinson

(57) **ABSTRACT**

A data storage master disk and method of making a data storage master disk. The data storage disk master is for use in a data storage disk replication process. The data storage disk molding processes produces replica disks having a surface relief pattern with replica lands and replica grooves. The method includes providing a master substrate. The master substrate is at least partially covered with a layer of photosensitive material. A surface relief pattern having master lands and master grooves is recorded in the data storage disk master, including the steps of exposing and developing the photosensitive material. The exposing and developing of a specified thickness of photosensitive material is controlled to form master grooves extending down to a substrate interface between the master substrate and the layer of photosensitive material, such that the width of the master grooves at the substrate interface corresponds to a desired width of the replica lands.

14 Claims, 9 Drawing Sheets



U.S. PATENT DOCUMENTS

5,723,033	A	3/1998	Weiss
5,739,972	A	4/1998	Smith et al.
5,751,510	A	5/1998	Smith et al.
5,889,756	A	3/1999	Ichihara et al.
6,190,838	B1	2/2001	Kerfeld

FOREIGN PATENT DOCUMENTS

JP	2-10536	1/1990
JP	2-244440	9/1990
JP	6-60441	3/1994
JP	8-147768	6/1996
JP	97097452	4/1997
JP	97138981	5/1997
WO	WO 00/48172	8/2000

OTHER PUBLICATIONS

E. O. Keizer, "VideoDisc Mastering," RCA Review, vol. 39, No. 1, Mar. 1978, pp. 60–86.

P. Trefonas III et al., "New Principle for Image Enhancement in Single Layer Positive Photoresists," SPIE vol. 771, *Advances in Resist Technology and Processing IV*, Mar. 1987, pp. 194–210.

S. Nakamura et al., "High Density Recording for Magneto–optical Disk Drive," IEEE Transactions on Magnetics, vol. 34, No. 2, Mar. 1998, pp. 411–413.

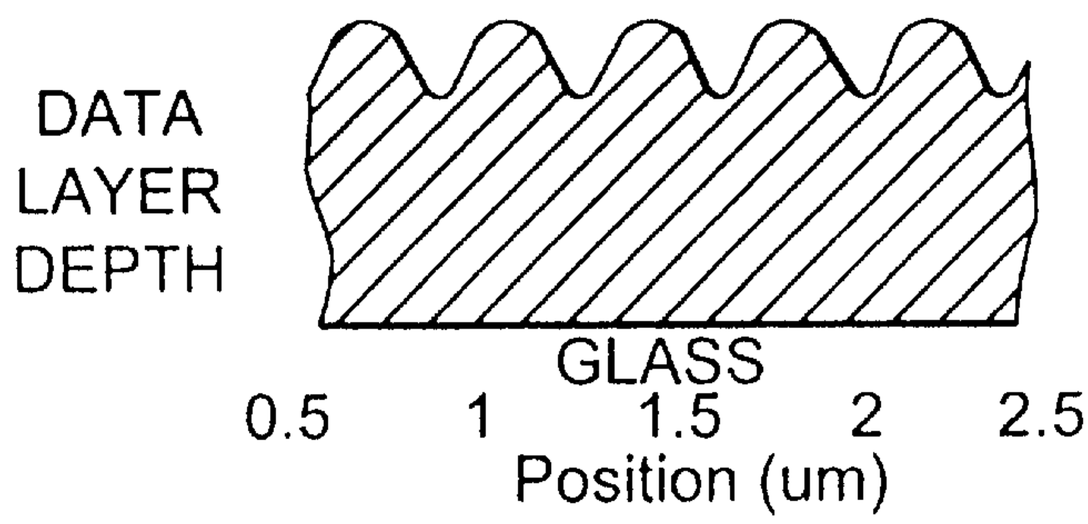


FIG. 1
PRIOR ART

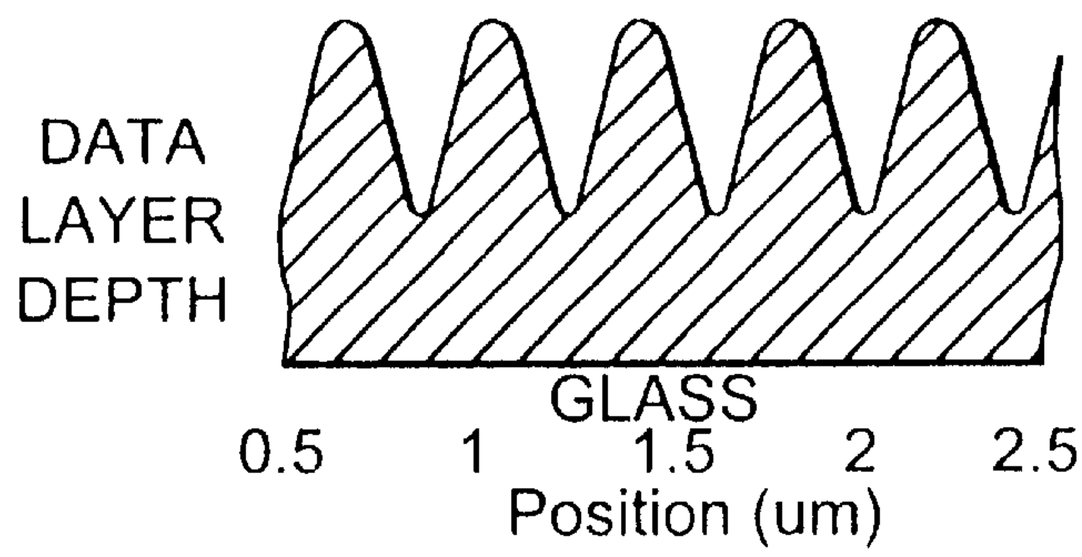


FIG. 2
PRIOR ART

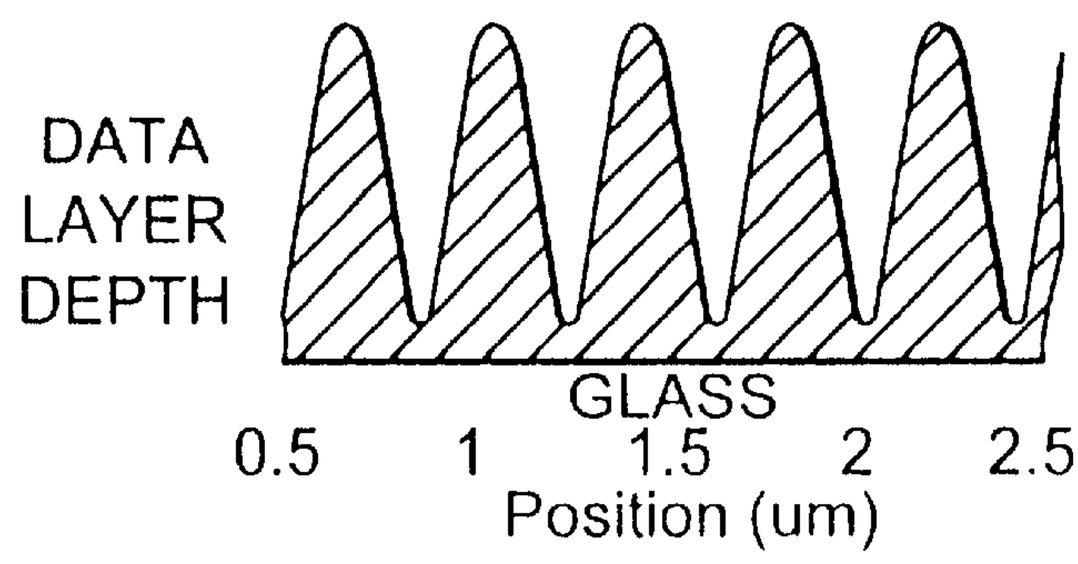


FIG. 3
PRIOR ART

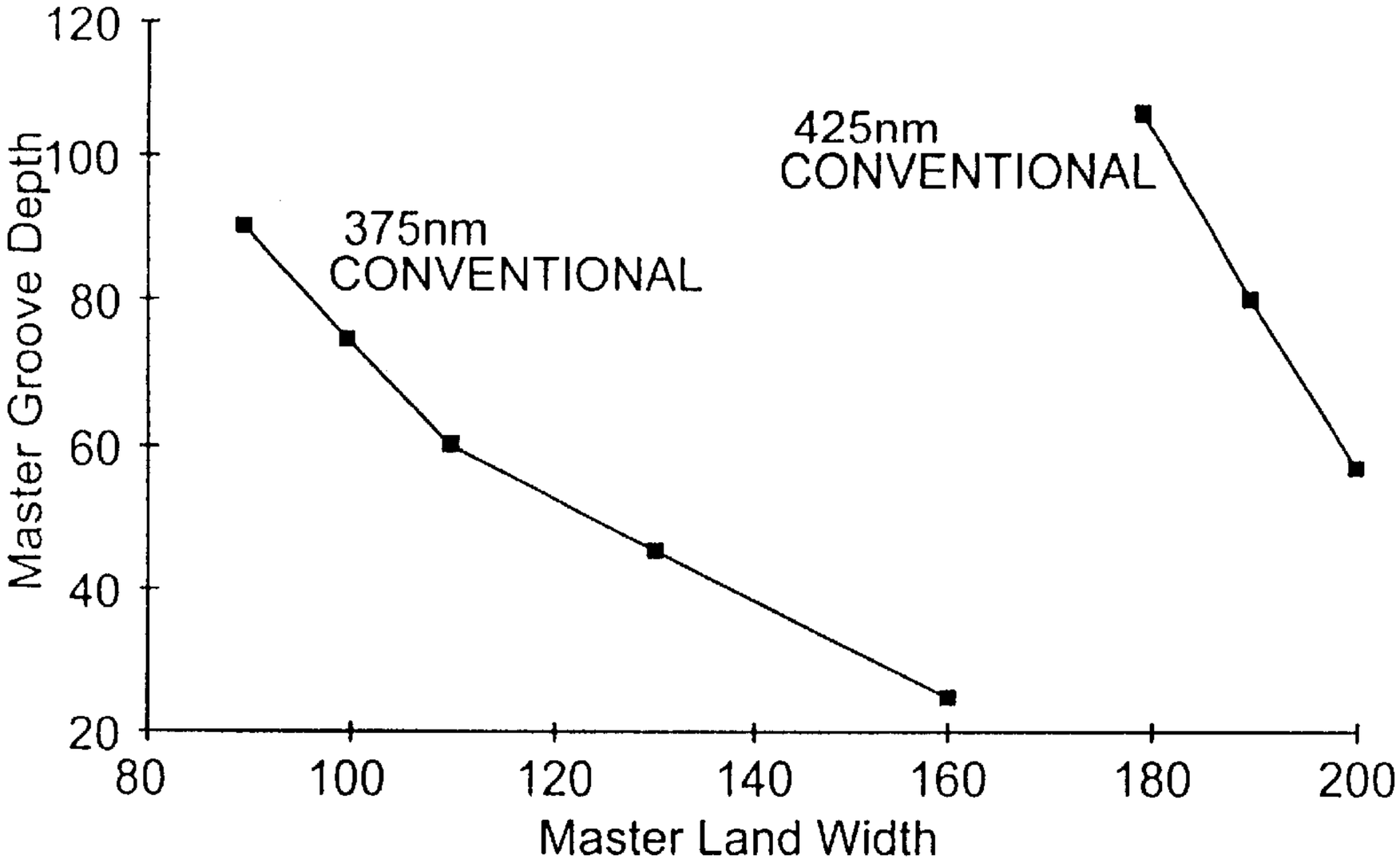

120
100
80
60
40
20
Master Groove Depth
375nm
CONVENTIONAL
425nm
CONVENTIONAL
80
100
120
140
160
180
200
Master Land Width

FIG. 4

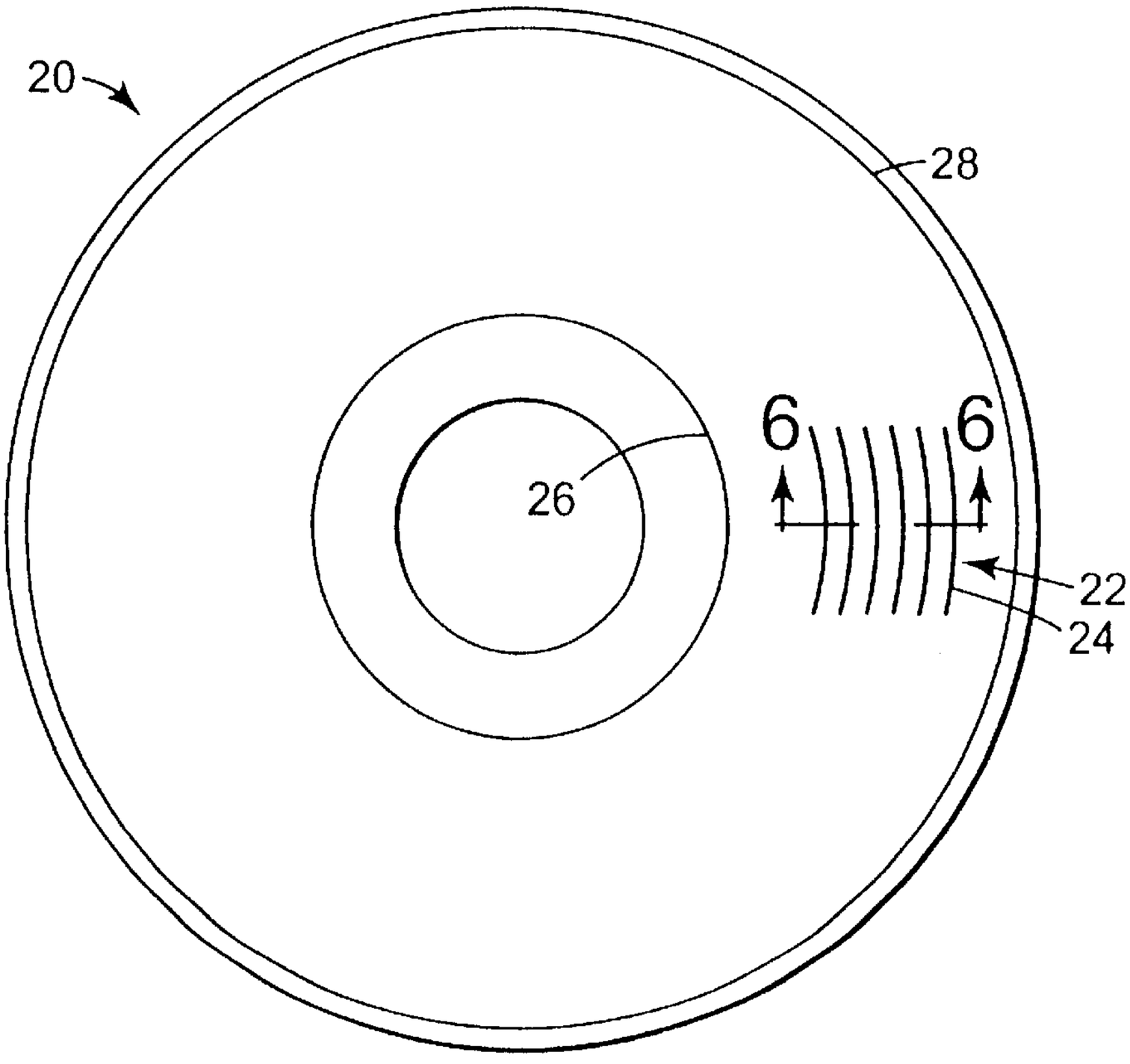

20
28
26
6
6
22
24

FIG. 5

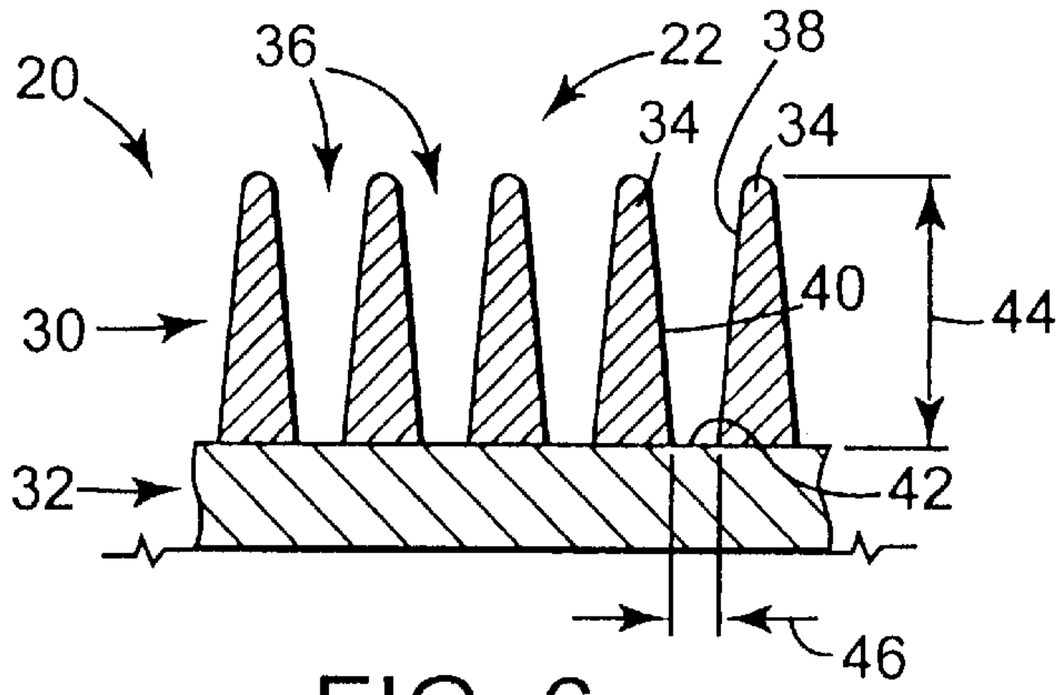


FIG. 6

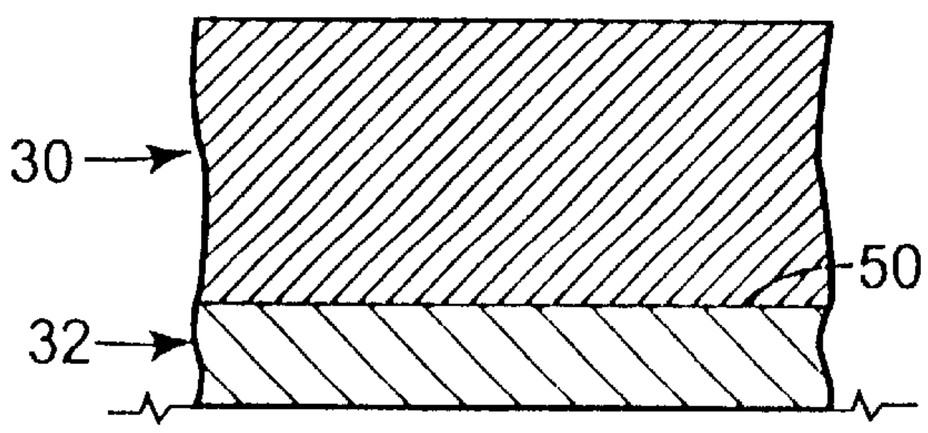


FIG. 7

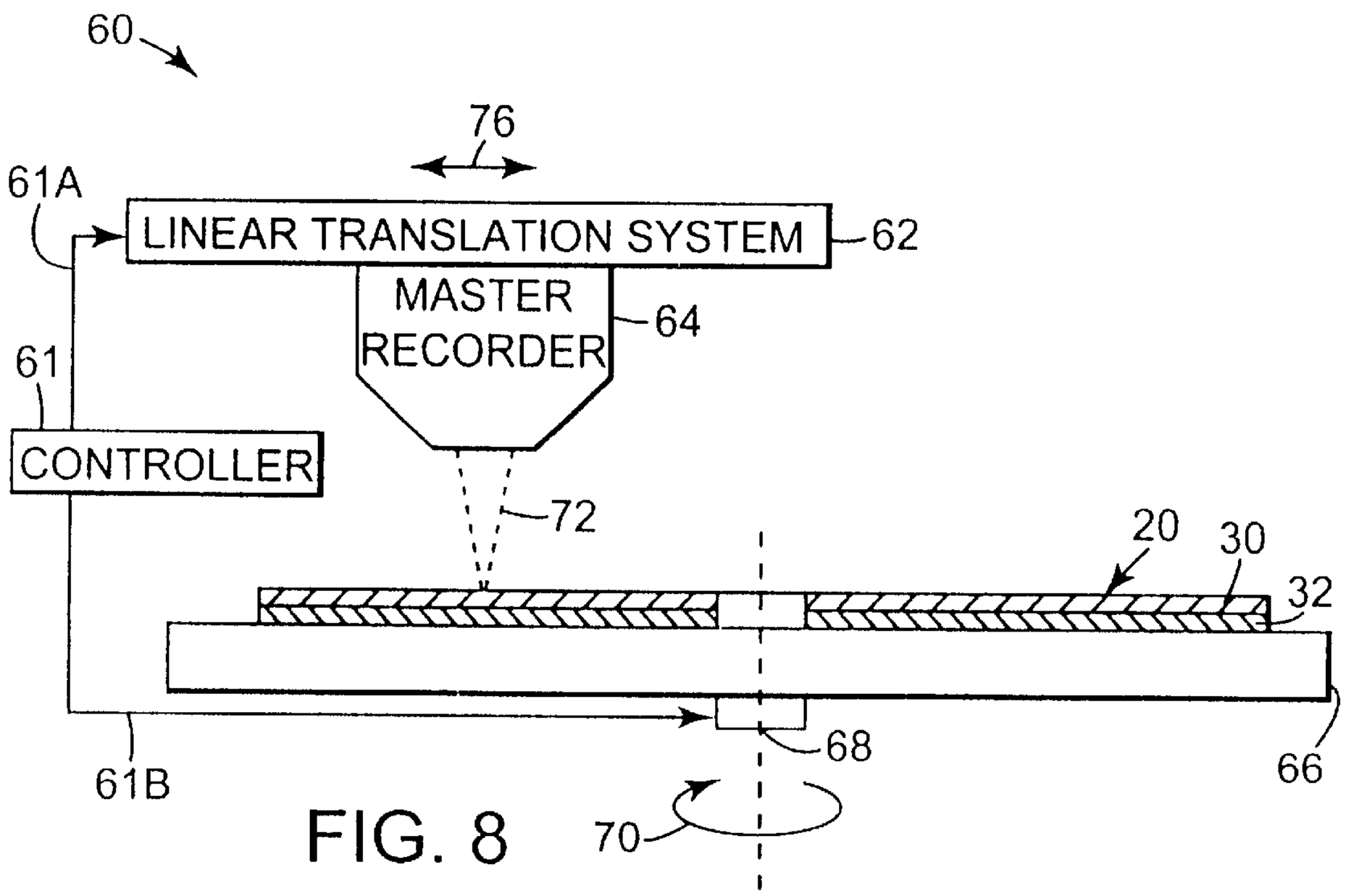


FIG. 8

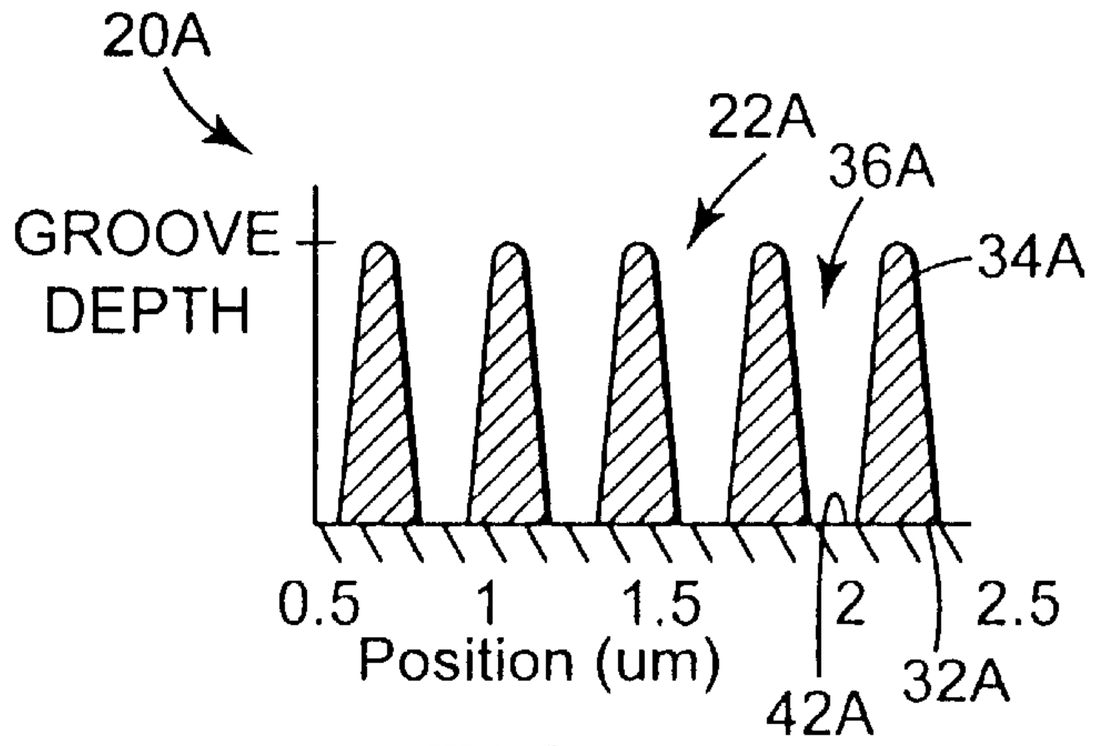


FIG. 9

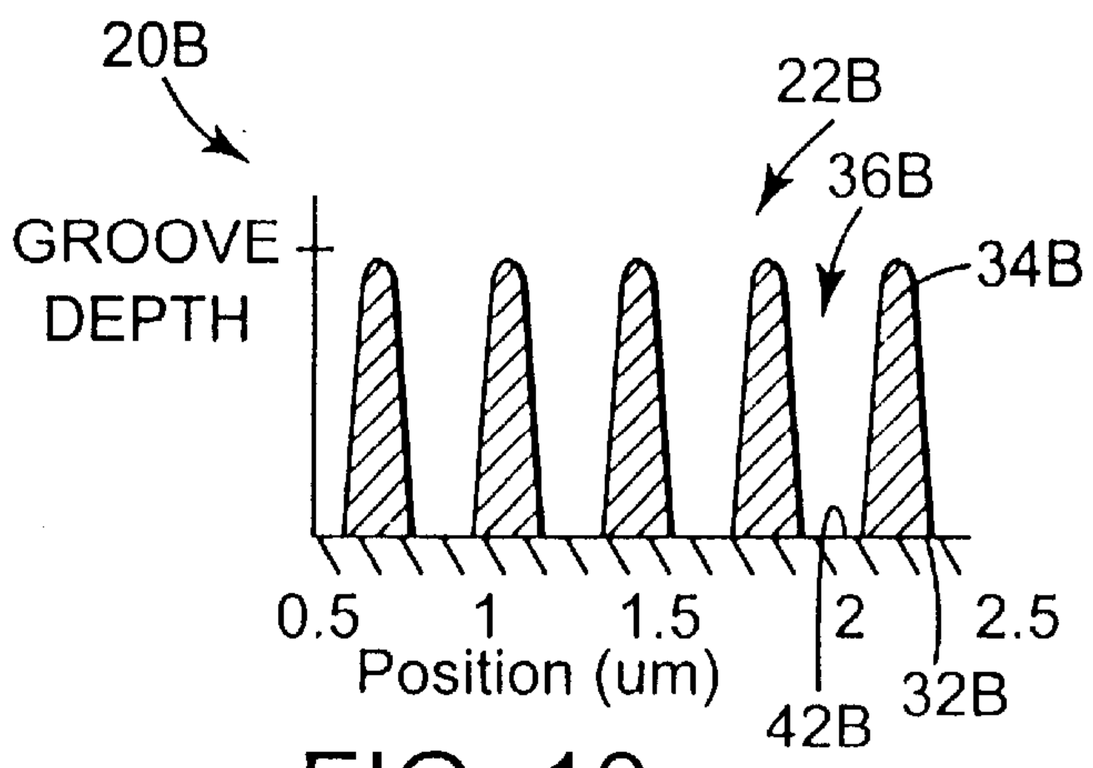


FIG. 10

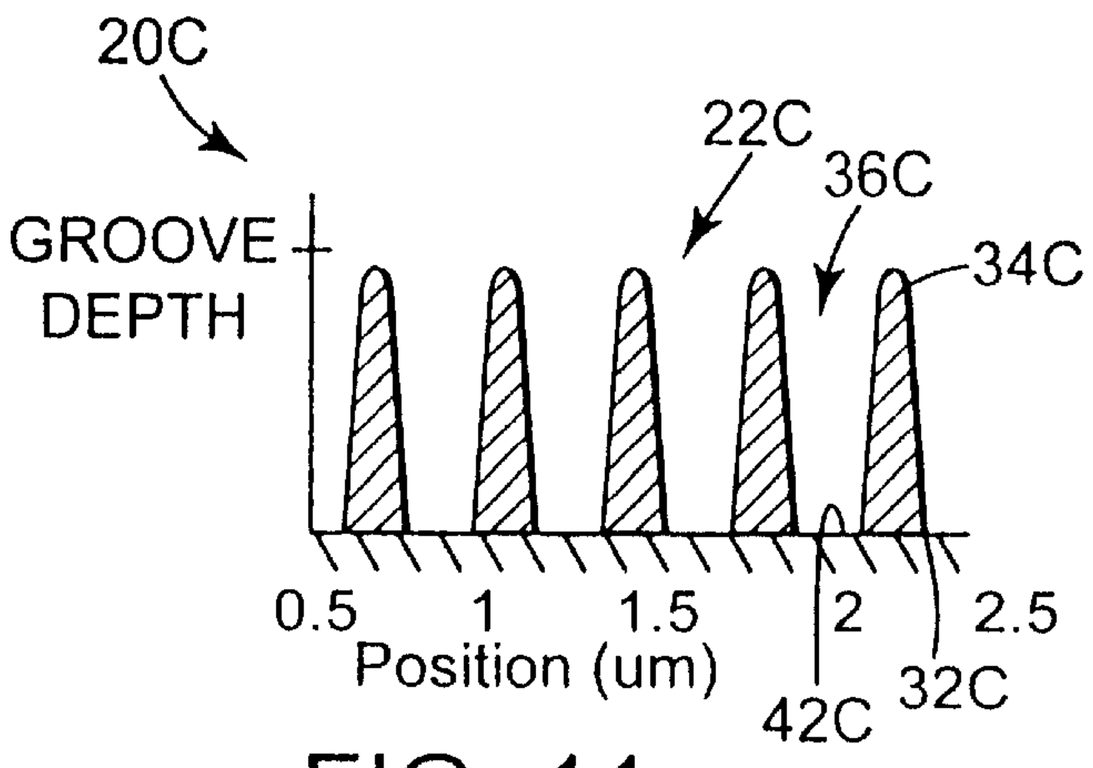


FIG. 11

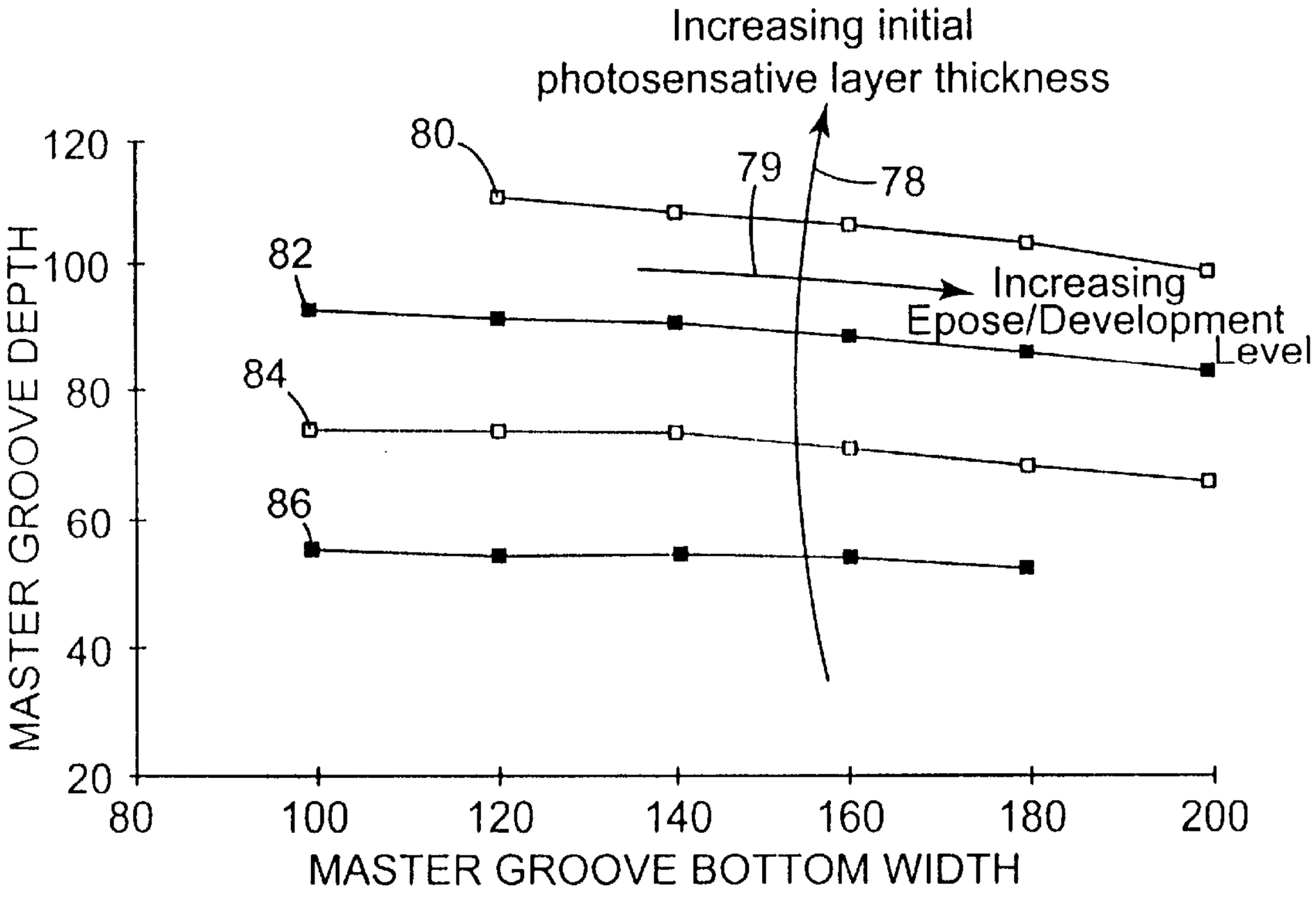

Increasing initial
photosensative layer thickness
80
79
78
82
Increasing
Epose/Development
Level
84
86
120
100
80
60
40
20
MASTER GROOVE DEPTH
80
100
120
140
160
180
200
MASTER GROOVE BOTTOM WIDTH

FIG. 12

0.425 EXAMPLES

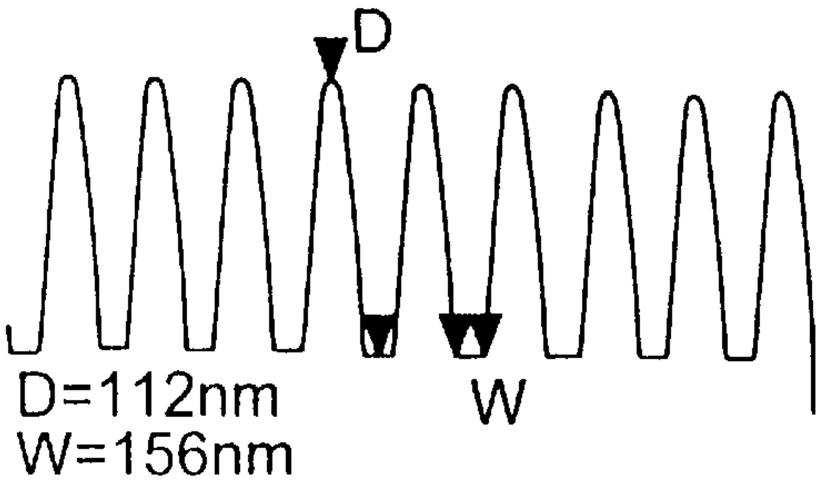


FIG. 13

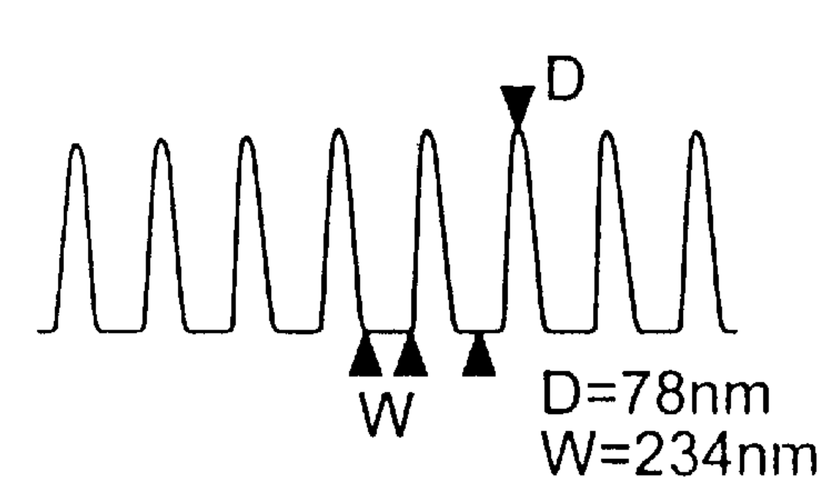


FIG. 14

FIG. 15

0.375 EXAMPLES

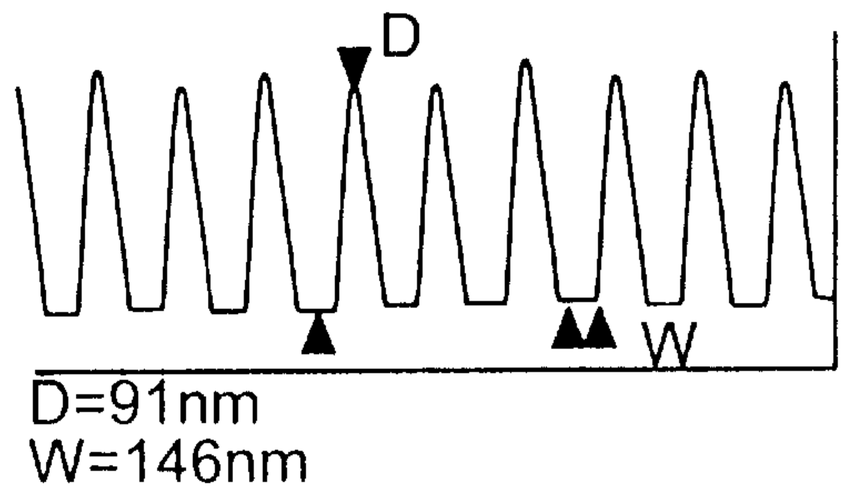


FIG. 16

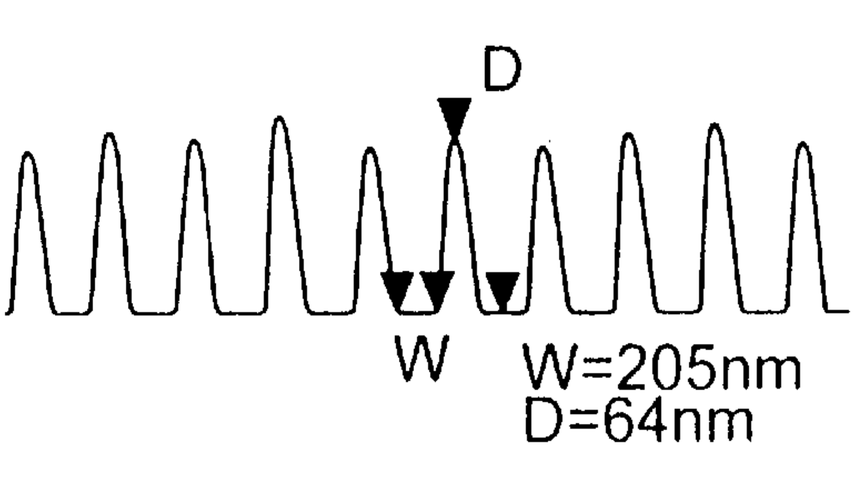


FIG. 17

FIG. 18

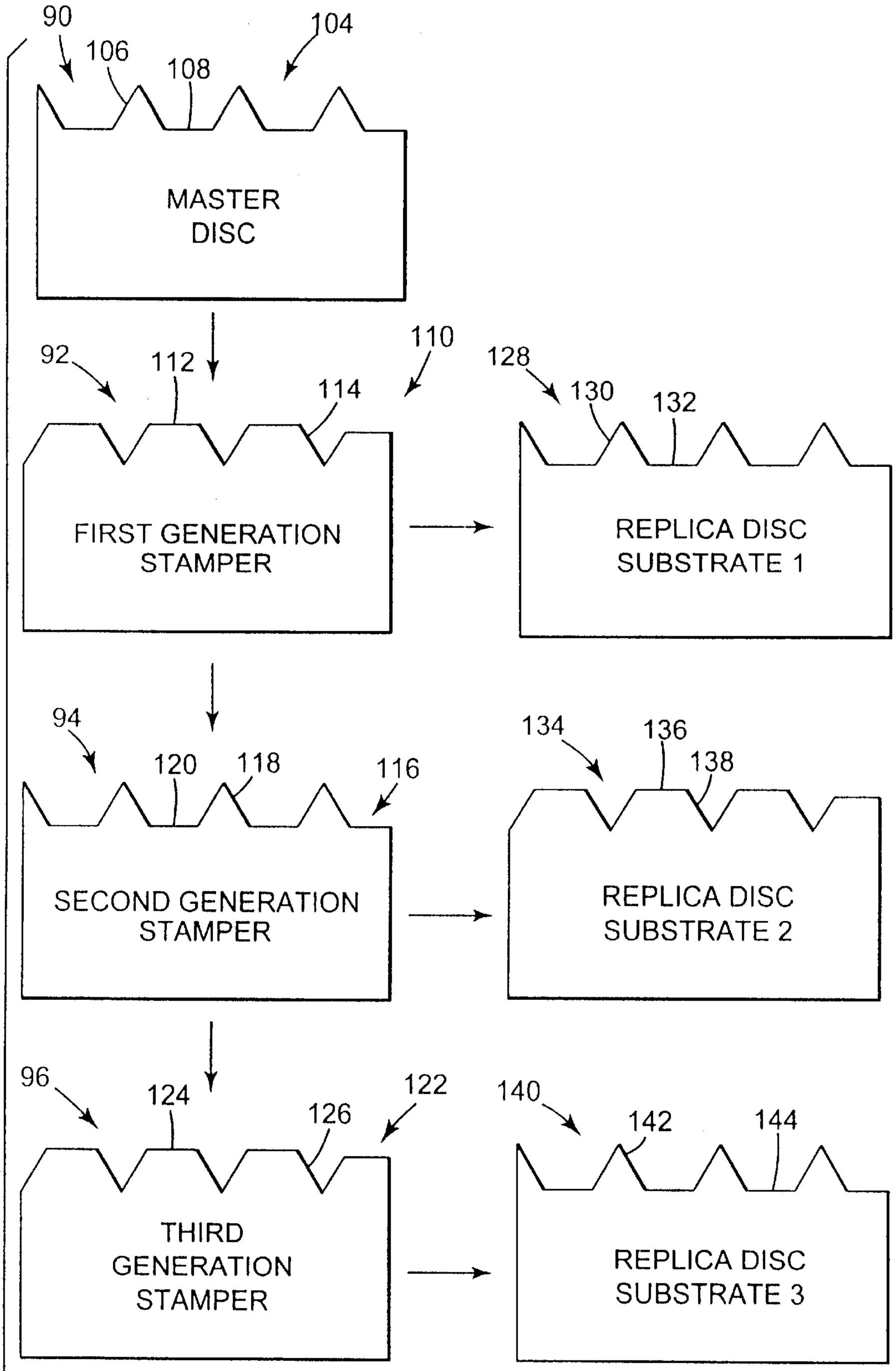

90
106
108
104
MASTER DISC
92
112
110
114
128
130
132
FIRST GENERATION STAMPER
REPLICA DISC SUBSTRATE 1
94
120
118
116
134
136
138
SECOND GENERATION STAMPER
REPLICA DISC SUBSTRATE 2
96
124
126
122
140
142
144
THIRD GENERATION STAMPER
REPLICA DISC SUBSTRATE 3

FIG. 19

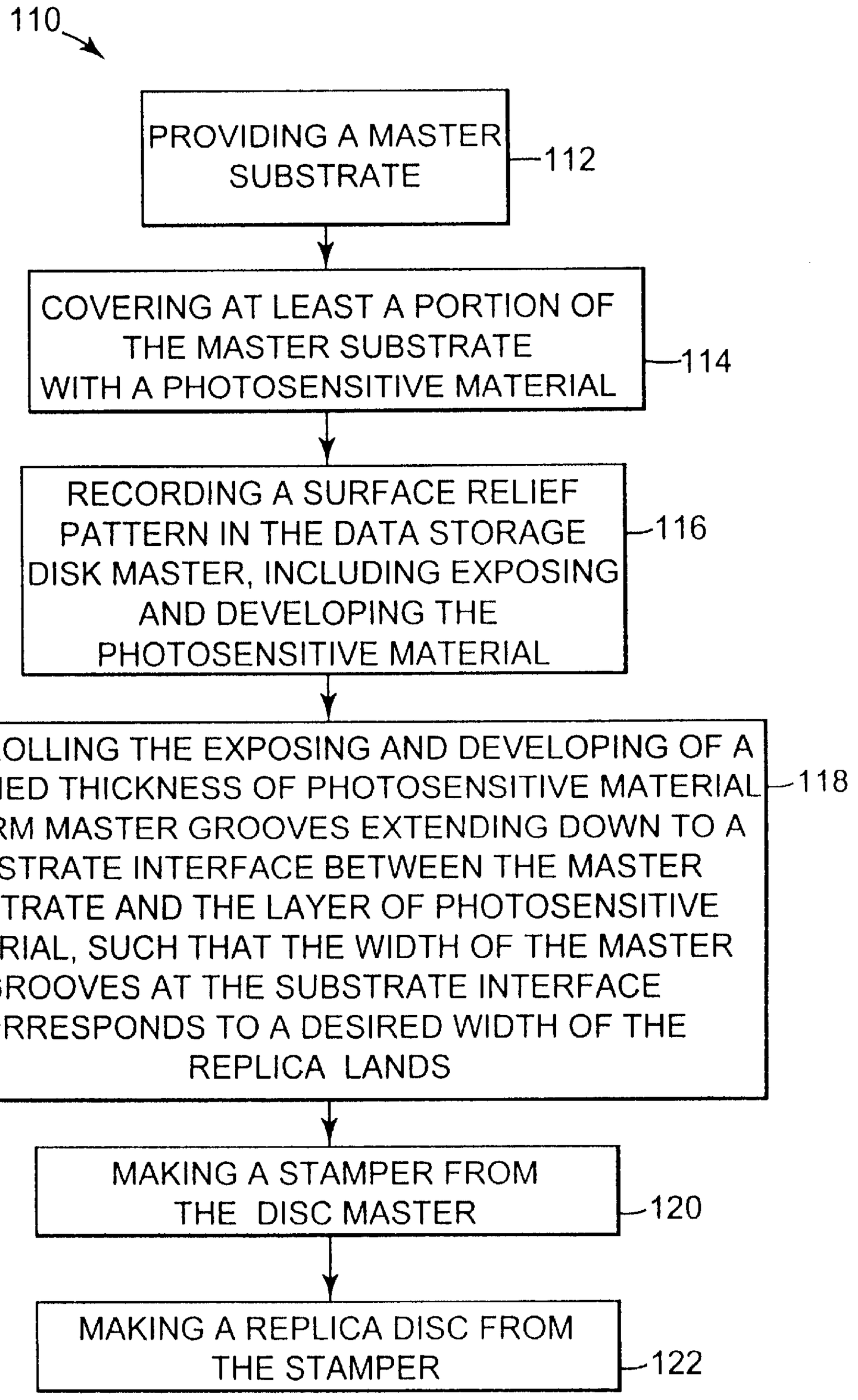

110
PROVIDING A MASTER SUBSTRATE
112
COVERING AT LEAST A PORTION OF THE MASTER SUBSTRATE WITH A PHOTOSENSITIVE MATERIAL
114
RECORDING A SURFACE RELIEF PATTERN IN THE DATA STORAGE DISK MASTER, INCLUDING EXPOSING AND DEVELOPING THE PHOTOSENSITIVE MATERIAL
116
CONTROLLING THE EXPOSING AND DEVELOPING OF A SPECIFIED THICKNESS OF PHOTOSENSITIVE MATERIAL TO FORM MASTER GROOVES EXTENDING DOWN TO A SUBSTRATE INTERFACE BETWEEN THE MASTER SUBSTRATE AND THE LAYER OF PHOTOSENSITIVE MATERIAL, SUCH THAT THE WIDTH OF THE MASTER GROOVES AT THE SUBSTRATE INTERFACE CORRESPONDS TO A DESIRED WIDTH OF THE REPLICA LANDS
118
MAKING A STAMPER FROM THE DISC MASTER
120
MAKING A REPLICA DISC FROM THE STAMPER
122

FIG. 20

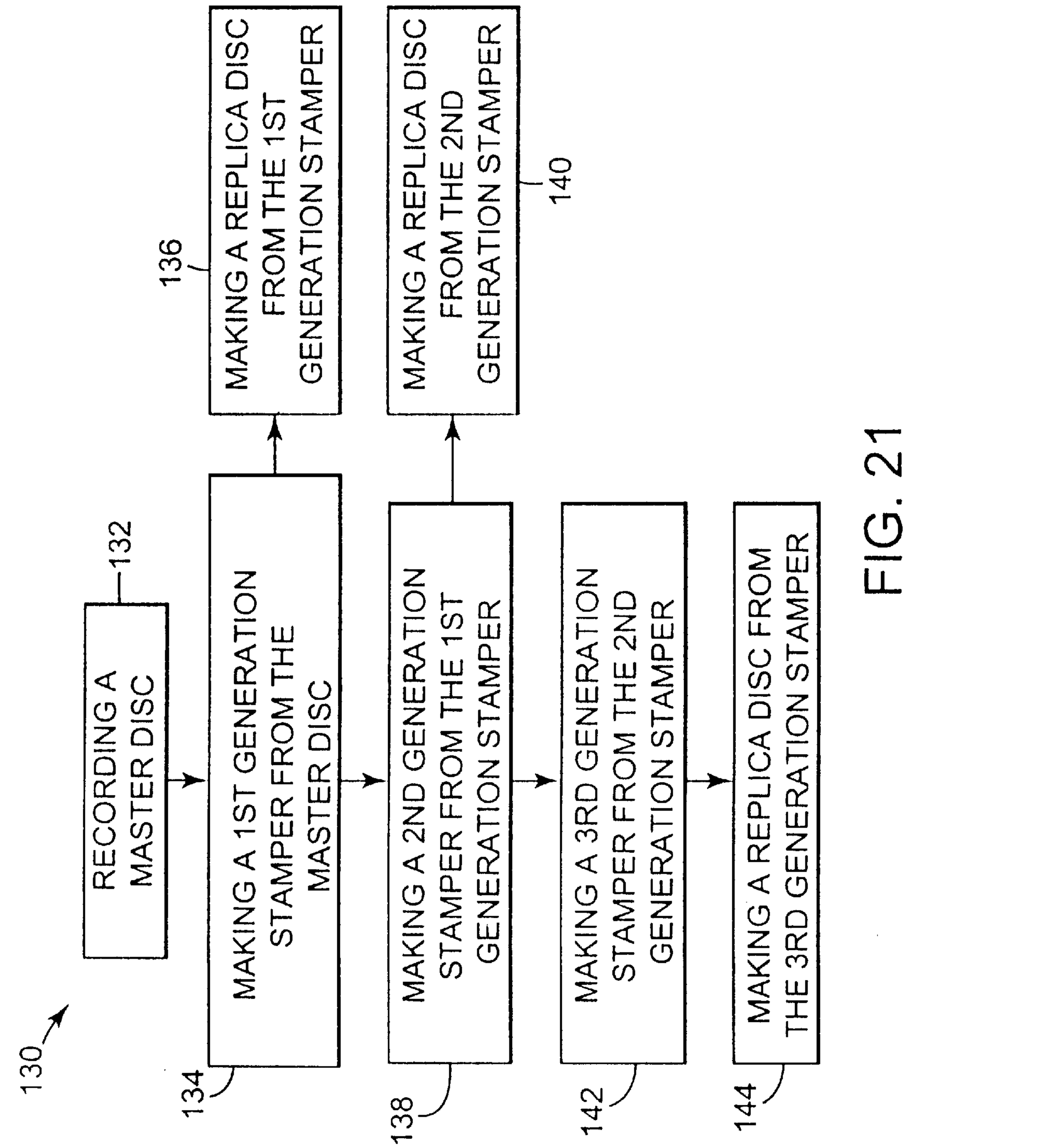

130
RECORDING A MASTER DISC
132
MAKING A 1ST GENERATION STAMPER FROM THE MASTER DISC
134
MAKING A 2ND GENERATION STAMPER FROM THE 1ST GENERATION STAMPER
138
MAKING A 3RD GENERATION STAMPER FROM THE 2ND GENERATION STAMPER
142
MAKING A REPLICA DISC FROM THE 3RD GENERATION STAMPER
144
MAKING A REPLICA DISC FROM THE 1ST GENERATION STAMPER
136
MAKING A REPLICA DISC FROM THE 2ND GENERATION STAMPER
140

FIG. 21

REVERSE OPTICAL MASTERING FOR DATA STORAGE DISKS

This is a divisional application of pending prior application Ser. No. 09/730,246 filed on Dec. 5, 2000, pending, which is a continuation-in-part of application Ser. No. 09/055,825 filed on Apr. 6, 1998, now abandoned.

TECHNICAL FIELD

The present invention relates generally to the field of manufacture of optical data storage disks, and in particular, to an optical disk mastering process for use in a disk molding process, capable of molding data storage disks containing a high density of information.

BACKGROUND OF THE INVENTION

Optical disks are produced by making a master which has a desired surface relief pattern formed therein. The surface relief pattern is created using an exposure step (e.g., by laser recording) and a subsequent development step. The master is used to make a stamper, which in turn is used to stamp out replicas in the form of optical master substrates. As such, the surface relief pattern, information and precision of a single master can be transferred into many inexpensive replica optical disk substrates.

During the mastering exposure step, the mastering system synchronizes the translation position of a finely focused optical spot with the rotation of the master substrate to describe a generally concentric or spiral pattern of a desired track spacing or "track pitch" on the disk. The generally spiral track forming the desired surface relief pattern as a result of the mastering process can be defined by high regions termed "lands" and lower adjacent regions termed "grooves" and/or pits (i.e., interrupted grooves). The recording power and size/shape of the focused optical spot (spot size) as well as the photosensitive material parameters determine the final geometry revealed in the master disk during the subsequent development step. Normal mastering practice uses high contrast positive photoresist for the photosensitive material.

Conventional mastering typically utilizes laser light with wavelength, λ, in a range of 350 nm$<\lambda<$460 nm focused through an objective with a numerical aperture (NA) of 0.75 nm<NA<0.90 to give a theoretical Gaussian spot size of:

SS=0.57λ/NA (full width at half maximum intensity (FWHM)). Thus, a 350 nm laser light with NA=0.9 gives a theoretical spot size 0.22 microns (FWHM) as the practical limit for conventional optics.

After the master is recorded, it is flooded with developer solution to reveal the exposure pattern applied by the master recording system. The dissolution of the photoresist in the developer solution is in proportion to the optical exposure previously received in the recording process. The dissolution rate of the photoresist can be modeled for given exposure and development conditions (see Trefonus, P., Daniels, B., "New Principal For Imaging Enhancement In Single Layer Positive Photoresist", Proc. of SPIE vol. 771 p.194 (1987), see also Dill F. et al., "Characterization of Positive Photoresists" IEEE Transactions on Electronic Devices, vol. ED-22 p. 445 (1975).) Expressions explained in these referenced technical papers can be used to model the effects of exposures from several adjacent tracks recorded in the photoresist and subsequently developed. The photoresist dissolution in the developer solution is in proportion to the optical exposure previously received (positive type resist). More accurately, the dissolution rate (R) is given by the Trefonas model as

$$R[nm/sec]=R_0\times(1-M)^q+R_b$$

Where R_0 and R_b are the dissolution rates of the fully exposed and unexposed photoresist (respectively), q is a resist parameter related to the resist contrast and M is the fractional unconverted photoactive compound in the resist. Typical values for commercially available resists are q=3, $10<R_0<200$ [nm/sec] and $R_b=0$ for normal developer concentrations. The M term is dependent in a pointwise fashion on how much exposure was received in the resist (E(x,y,z)) and the resist's parametric sensitivity "C" per the Dill convention:

$$M(x,y,z)=\exp\{-C\times E(x,y,z)\}.$$

Since optical disk mastering typically uses only 50–200 nm of photoresist thickness, the z-dependence of exposure can safely be ignored so that the above equations can be combined to give

$$R=R_0(1-\exp\{-CE(x,y,)\})^q;$$

or, with the exposure profile explicitly circular gaussian we may simplify to

$$R=R_0(1-\exp\{-CkP\ \exp\ [-r^2/SS^2]\})^q;$$

Where r measures the radial distance from the center of the spot ($r^2=x^2+y^2$), p is the recording power and k is a normalization constant for the guassian function. This dissolution rate, multiplied by the development time (t_d), gives the depth of photoresist lost from its initial coating thickness (T_0), so that the final resist thickness (T(t)) is given by $T(td)=T_0-t_d\ R_0(1-\exp\{-CkP\ \exp\ [-r^2/SS^2]\})^q$; From this expression one can see now optical exposure (P), development (t_d, R_0) and photoresist thickness (T_0) determines final surface relief pattern.

In some aspects, these expose/development processes may be compared with conventional photography. In photography, either exposure or development may be controlled/adjusted as necessary to obtain desired final development pattern. In this sense, one may consider the expose/development level as one process variable which may alternatively be controlled by recording power, development time, developer concentration, etc.

In the mastering process, it is desirable to simultaneously obtain wide lands (for user recorded features) and grooves of suitable depth for adequate tracking signals (e.g., greater than 50 nm). Higher density data storage disks often require the storage or a greater amount of information within the same or smaller size of disk area, resulting in smaller track pitch (i.e., distance between tracks) design criteria.

Attempts have been made to meet these design criteria. In prior art FIGS. **1–3**, surface relief patterns of exemplary master disks formed using conventional disk mastering techniques are illustrated using the above expressions to model the effects of exposures from several adjacent tracks recorded in the photoresist layer and then developed. These comparisons assume (1) typical photoresist and developer parameters, (2) constant development time (=40 sec.), (3) SS=0.23 microns, (4) track pitch of 0.375 microns and initial photoresist thickness of 100 nm. As recording power (or alternatively, development time) is increased to obtain deeper grooves, the residual land width diminishes and lands become more rounded due to overlap exposure from adjacent tracks. Partially developed photosensitive material exhibits a granular roughness greater than that of the photosensitive material as initially coated on the disk. Roughness of lands worsens with deepening of grooves, resulting in additional noise in data readback.

More problems occur when the track pitch approaches the finite size of the mastering spot size. For formats where the desired track pitch is much larger (>2×) than the finite size of he mastering spot size (ss), the photosensitive material erosion of the lands is negligible and conventional mastering can provide wide lands with a >50 nm groove depth. However, for formats where the track pitch is <2× larger than the spot size, conventional mastering requires a compromise of either land width, groove depth, or both (due to overlap exposure from adjacent tracks).

In FIG. **4**, exemplary embodiments of the mandatory link between land width and groove depth when using conventional mastering processes is illustrated. (Examples of 0.375 micron and 0.425 micron track pitch with 0.22 micron recording spot size). As the groove depth increases, the land width decreases. The master surface relief pattern geometries (i.e, land width/groove depth) are constrained for given conditions of track pitch and mastering spot size. This means the designer may not independently specify the desired parameters for replica land width and replica groove depth.

A secondary problem for conventional mastering is that the land width precision is limited by mechanical track pitch precision (e.g., mechanical precision of master recording system), which is increasingly difficult to control as track pitch decreases.

SUMMARY OF THE INVENTION

The present invention provides a data storage master disk and method of making a data storage master disk wherein the user may independently specify the parameters of replica land width and replica groove depth. The data storage master disk is for use in a data storage disk molding process for producing replica disks which are capable of storing a high capacity of information using a variety of disk formats.

In a first embodiment, the present invention provides a method of making a data storage master disk for use in a data storage disk molding process. The data storage disk molding process produces replica disks having a surface relief pattern with replica lands and replica grooves. The method includes the step of providing a master substrate. The master substrate is covered with a layer of photosenstive material having a specified thickness. A surface relief pattern having master lands and master grooves is recorded in the data storage master disk, including the steps of exposing and developing the photosensitive material. The exposing and developing of a specified thickness of a photosensitive material is controlled to form master grooves extending down to a substrate interface between the master substrate and the layer of photosensitive material, such that the width of the master grooves at the substrate interface corresponds to a desired width of the replica lands.

The thickness of the photosensitive material is specified and controlled to correspond to a desired depth of the replica grooves. In another aspect, the thickness of the photosensitive material is specified and controlled in dependence on master recording system spot size, desired track pitch, and desired depth of replica grooves. The step of controlling the exposure and development of the data storage master disk may include the step of controlling the exposing and developing of the photosensitive material to obtain a flat master groove bottom. In another aspect, the step of controlling the exposure and development of the data storage master disk includes the step of controlling the exposing and developing of the photosensitive material to obtain a smooth, flat master groove bottom, with smoothness determined by the master substrate.

The step of controlling the exposing and developing of the photosensitive material may include the step of controlling optical energy for exposing the photosensitive material to a degree sufficient to obtain a desired master groove bottom width after development and removal of the photosensitive material. In another aspect, the step of controlling the exposing and developing of the photosensitive material may include the step of controlling the development of the photosensitive material to a degree sufficient to obtain a desired master groove width after development and removal of the exposed photosensitive material.

The step of exposing and developing the data storage master disk may include the step of forming a groove bottom, wherein the groove bottom is flat relative to the master land. The step of exposing and developing the data storage master disk results in the data storage master disk having a master surface relief pattern defined by the master lands and the master grooves, wherein the surface relief pattern of the replica disks has an orientation which is inverse the orientation of the data storage master disk surface relief pattern.

The present invention may further provide the step of polishing the master substrate optically smooth; and forming a smooth master groove bottom using the master substrate. In one aspect, the step of providing a master substrate includes forming a master substrate made of glass. Preferably, the glass is polished. The photosensitive material may be bonded to the master substrate with or without intermediate layers.

The present invention may further provide for forming a first stamper using the data storage master disk. Replica disks are made using the first stamper. The step of making replica disks using the data storage master disk may be accomplished using a multiple generation stamper process.

In another embodiment, the present invention provides a method of making a replica disk from a master disk using an inverse stamping process. The replica disk is capable of storing high volumes of information. The replica disk includes a surface relief pattern with replica lands and replica grooves. The method includes the step of providing a master substrate. At least a portion of the master substrate is coated with a layer of photosensitive material to form the master disk. A surface relief pattern having master lands and master grooves is recorded in the master disk, including the steps of using a laser beam recorder for exposing the photosensitive material in a desired track pattern having a track pitch, and developing the photosensitive material. The exposing and developing of the photosensitive material is controlled for forming master grooves extending down to a substrate interface between the master substrate and the photosensitive material, such that the width of the master grooves at the substrate interface corresponds to a desired width of the replica lands. A first stamper is formed from the master disk. A second stamper is formed from the first stamper. A replica disk is formed from the second stamper, the replica disk including a surface relief pattern having an orientation which is the inverse of the master disk.

The present invention may further provide the step of controlling the thickness of the layer of the photosensitive material to correspond to a desired depth of the replica grooves. The specified and controlled thickness of the photosensitive material depends on master recording system spot size, desired track pitch, and desired depth of replica grooves.

The step of controlling the exposing and developing of the photosensitive material may include the step of controlling

the exposing and developing of the photosensitive material to obtain a flat master groove bottom. Recording a desired track pitch in the photosensitive material may further include the use of a focused laser beam at a spot size which is greater than one half of the track pitch.

The step of a master substrate may include providing a master substrate made of glass. Further, the master substrate may be polished.

In one aspect, the desired track pattern is a spiral track defined by adjacent master lands and master grooves, wherein the steps of exposing/developing the master disks includes forming a wide, flat master groove bottom defined by the disk substrate. The step of recording the master disk includes forming master groove bottoms having a width which does not necessarily depend on the depth of the master groove for a desired track pitch. The resulting depth of the master groove is dependent on the specified thickness of the photosensitive material and the cumulative optical exposure received by the photosensitive layer at a position half way between two adjacent tracks. In particular, this depends on the desired groove bottom width and the ratio of master recording spot size to desired track pitch.

In another embodiment, the present invention provides a master disk. The master disk includes a master substrate. A layer of photosensitive material covers at least a portion of the master substrate. The photosensitive material includes a surface relief pattern in the form of a track pattern defined by adjacent master lands and master grooves. The master grooves extend down to the disk substrate, the master grooves including a master groove bottom and the master lands including a master land top, wherein the master groove bottom is wider than the master land top.

The master groove bottom is generally flat. In particular, the master groove bottom is flat relative to the master land top, and in particular, the master groove bottoms may be wide and flat relative to the master land tops. Preferably, the master groove bottoms include sharp corners. Additionally, all of the master groove bottoms on the exposed/developed master disk are level with each other to the precision of the master substrate flatness. This is important in flying head media applications, such as near field recording techniques, where small lenses fly in proximity to the replica disk surface.

The master grooves may include a groove depth which is proximate the thickness of the photosensitive material for cases where the track pitch is greater than approximately 1.6 times the spot size. In one aspect, the master grooves include a groove depth which is greater than 50 nanometers, track pitch is less than two times the mastering system spot size, and the width of the master groove bottom is greater than 25 percent of desired track pitch. In another aspect, the width of the master groove bottom is greater than 50 percent desired track pitch.

In another embodiment, the present invention provides a disk including a replica substrate having a first major surface and a second surface. The first major surface includes a surface relief pattern in the form of a track pattern defined by adjacent lands and grooves. The track pattern having a track pitch less 0.425 nanometers, wherein the grooves extend down into the disk substrate. The grooves include a groove bottom and the replica lands include a land top, wherein the land top is flat. This is particularly important in near field recording techniques, wherein lens-to-media-surface separation is extremely critical.

In one aspect, the land top has a width greater than 25 percent of track pitch. In one preferred aspect for the track pitch less than or equal to 400 nanometers, the groove depth is greater than 80 nanometers and the land width is greater than 160 nanometers. Preferably, the land top is smooth and has sharp edges. In one preferred embodiment, the land tops are level with each other to the precision of the flatness of the master disk substrate. The land tops are level and at the same elevation relative to the second major surface. This is important in flying head media applications, such as near field recording techniques, where small lenses fly in proximity to the replica disk surface.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings are included to provide a further understanding of the present invention and are incorporated in and constitute a part of this specification. The drawings illustrate the embodiments of the present invention and together with the description serve to explain the principals of the invention. Other embodiments of the present invention and many of the intended advantages of the present invention will be readily appreciated as the same become better understood by reference to the following detailed description when considered in connection with the accompanying drawings, in which like reference numerals designate like parts throughout the figures thereof, and wherein:

FIG. **1** is a partial cross section illustrating the surface relief pattern of a prior art recorded master disk;

FIG. **2** is a partial cross-section illustrating the surface relief pattern of another master disk made using a prior art recording process;

FIG. **3** is a partial cross-section illustrating the surface relief pattern of another master disk made using a prior art recording process;

FIG. **4** is a graph illustrating master groove depth versus master land width for a master disk made using prior art mastering/recording techniques;

FIG. **5** is a plan view illustrating one exemplary embodiment of a recorded master disk made using a data storage disk mastering process in accordance with the present invention;

FIG. **6** is an enlarged partial cross-sectional view taken along line **6**—**6** of FIG. **5**;

FIG. **7** is an enlarged partial cross-sectional view illustrating a step in making a master disk in accordance with the present invention;

FIG. **8** is a diagram illustrating another step in making a master disk in accordance with the present invention;

FIG. **9** is a diagram illustrating one exemplary embodiment of the surface geometry of a master disk made using the process in accordance with the present invention;

FIG. **10** is a diagram illustrating another exemplary embodiment of the surface geometry of a master disk made using the process in accordance with the present invention;

FIG. **11** is a diagram illustrating another exemplary embodiment of the surface geometry of a master disk made using the process in accordance with the present invention;

FIG. **12** is a graph illustrating maximal master groove depth versus master groove bottom width for examples of master disks made using the mastering process in accordance with the present invention;

FIGS. **13**–**18** illustrate experimental atomic force microscope traces of several differing surface relief geometries for master disks recorded at 0.375 and 0.425 micron track pitch using the mastering process in accordance with the present invention;

FIG. **19** is a diagram illustrating groove orientation for replica disks made from a master disk in accordance with the present invention, using a multiple generation disk molding/replication process;

FIG. **20** is a block diagram illustrating a data storage disk mastering process in accordance with the present invention; and

FIG. **21** is a block diagram illustrating a process for making a replica disk using a master disk in accordance with the present invention.

DETAILED DESCRIPTION

The present invention includes a data storage master disk and optical disk mastering process for making the unique data storage master disk. The process in accordance with the present invention provides for a master data storage disk having grooves which extend down to the master substrate, resulting in deep, flat, and wide master disk grooves. The master disk can be used in a disk molding process which includes a reverse mastering/inverse stamping process, resulting in replica disks having wide, flat lands with sharp edges, and deep grooves relative to replica disks formed using conventional mastering processes. As such, the present invention is particularly useful in enabling flexible design of surface relief geometry for molded data storage disks containing a high density of information. This includes the ability to create wide, flat land features even in replica disks having a track pitch of less than two times the mastering system laser beam spot size.

In FIG. **5**, a data storage master disk **20** in accordance with the present invention is generally shown. Master disk **20** may be used as part of a disk replication process (e.g. a disk molding process) for producing various formats of optical data disks. The data features on the optical data disks may include data pits, grooves, bumps or ridges, and land or land areas. This includes current formats of audio CD, CD-ROM and video disk, such as DVD, as well as future formats which use data features described herein. The definition of optical data disks may include various types of recordable optical disks (e.g., CDR, magnetooptic, or phase-change disk formats, which commonly use features, such as grooves or pits, for tracking and address identification, even though data is subsequently recorded by the users.

Master disk **20** includes a surface relief pattern (i.e., surface geometry) in the form of "data tracks" **22** (shown enlarged for clarity) which may include features representing data encoded therein or which allow the storage, reading, and tracking of data thereon. Data tracks **22** on the optical disk can be arranged in a spiral track **24** originating at the disk center **26** and ending at the disk outer edge **28**, or alternatively, the spiral track **24** may originate at the disk outer edge **28** and end at the disk center **26**. The data can also lie in a series of concentric tracks spaced radially from the disk center **26**. Master disk **20** may or may not include a center hole, and may be hubbed or hubless.

In, FIG. **6**, a partial cross-sectional view illustrating one exemplary embodiment of master disk **20** in accordance with the present invention is shown. Master disk **20** includes data layer **30** and master substrate **32** (a portion of which is shown). The data layer **30** includes a surface relief pattern shown as data tracks **22**. The data tracks **22** are defined by a series of adjacent master lands **34** and master grooves **36** formed in the data layer **30** (e.g., which form spiral track **24**). The master groove sides **38**, **40** are defined by adjacent master lands **34**, and include a master groove bottom **42** which is defined by the master substrate **32**. Master substrate **32** provides for a wide, flat and smooth master groove bottom **42**.

Data layer **30** is made of a photosensitive material, and more preferably, is made of a photopolymer or photoresist. Master grooves **36** have a depth **44** which is equal to the height of master lands **34** relative to master substrate **32**, and related to the initial thickness of data layer **30**. Master groove depth **44** may further be dependent on mastering spot size, track pitch, and photoresist contrast. Preferably, master grooves **36** have a depth greater than 50 mm, and which typically ranges between 50 nm and 120 nm. Master groove bottom **42** is preferably flat and smooth as defined by master substrate **32**, having a width **46** which is preferably greater than 35 percent of the desired track pitch.

In one preferred embodiment, master substrate **32** is made of glass, and is preferably polished and/or optically smooth. The master substrate **32** typically varies in thickness between 5 mm and 6 mm. Data layer **30** can be bonded to master substrate **32**. In particular, data layer **30** may be coated directly to master substrate **32** or may include an intermediate layer (which may be a bonding layer).

The disk mastering process in accordance with the present invention provides for master disk **20** having relatively deep master grooves **36** with wide, flat master groove bottoms **42**. As such, when master disk **20** is used in a reverse optical disk mastering process, the master lands and master grooves translate into a replica disk having relatively deep grooves and wide flat lands. Such characteristics are preferred for many high density and writeable optical disk formats.

The master groove bottoms defined by the disk mastering process in accordance with the present invention are flat (as opposed to rounded in the conventional process) with smoothness defined by the master substrate (e.g., polished glass) and includes sharp corners. When used in connection with an inverse stamping process, this corresponds to replica disks having wide, flat smooth lands with sharp corners, and deep grooves. Wide, flat lands are advantageous for positioning user recorded data thereon. The sharp corners provide domain confinement for user recorded data (e.g., applications wherein data is magneto-optically recorded on the tops of lands). The wide, flat lands with sharp corners and deep grooves provide for improved tracking or trackability of the media substrate. The replica disk land tops are very smooth, due to the groove bottoms **42** which are defined by the master substrate **32**, which is preferably optically polished glass. The smoothness of the land tops is defined by the substrate interface between the master substrate **32** and the layer of photosensitive material **30**. Smoothness of land tops results in a reduction of noise in subsequent readout of data from the disk.

Further, the wide, flat lands are level with each other, due to the groove bottoms **42** being defined by the master substrate **32**. The flat lands are level with each other and at the same elevation, enhancing the flyability of the disk substrate for flying head applications.

Referring to FIGS. **7** and **8**, a method of making an optical disk master for use in a data storage disk molding process, in accordance with the present invention, is illustrated. In FIG. **7**, master substrate **32** is provided which is preferably made of glass. Master substrate **32** typically ranges in thickness between 5 mm and 6 mm. Master substrate **32** includes major surface **50**. Preferably, major surface **50** is polished optically smooth. Major surface **50** is at least partially covered (e.g., coated) by data layer **30**. Data layer **30** may also be coated over an intermediate (e.g., bonding) layer **60** (not shown).

Referring to FIG. **8**, master disk **20** is positioned on a master recording system (e.g., a laser recorder or a mask

recording system). In one exemplary embodiment, the master record system **60** includes controller **61**, linear translation system **62**, master recorder **64**, and recording table **66**. Master recording system **60** provides for controlled exposure of master disk **20** with a focused spot of laser light to encode the desired surface relief pattern (i.e., geometry) or data tracks therein.

Master disk **20** is placed on recording table **66**, and can be registered (e.g., centered) about a center axis **68**, relative to master recorder **64** using techniques as known in the art, such as through the use of a spindle, or hubbed master disk **20**. Recording table **66** is rotatable about the center axis **68**, indicated by rotation arrow **70**, for rotation of master disk **20** during the disk recording process. Master recorder **64** modulates and focuses a laser beam **72** for exposure of data layer **30** in a desired pattern. Further, master recorder **64** is mechanically coupled to linear translation system **62** which provides for axial movement of master recorder **64** relative to center axis **68**, indicated by directional arrow **76**.

Controller **61** is coupled to linear translation system **62** and master recorder **64** (indicated at **61**A) and is coupled to recording table **66** (indicated at **61**B). The controller **61** operates to synchronize the translation position of the finally focused laser beam **72** with the rotation **70** of master disk **20** to expose spiral track **24** in data layer **30**. Further, controller **61** may operate to modulate laser beam **72** to expose pit regions (interrupted grooves) in the header area of the disk. Controller **61** can be a microprocessor based programmable logic controller, a computer, a sequence of logic gates, or other device which may be capable of performing a sequence of logical operations.

In accordance with the present invention, controller **61** operates to control the optical energy of master recording system **60** for exposing the photosensitive material of master disk **20** to a degree sufficient to obtain a desired master groove bottom width after development and removal of the exposed photosensitive material. Controlling the optical energy can include controlling either the recording power or controlling the recording speed for exposing the photosensitive material to a degree sufficient to obtain a desired master groove bottom width after development and removal of the exposed photosensitive material. For example, controller **61** may operate to increase the recording power or decrease the recording speed, thereby increasing optical exposure of the photosensitive material.

The laser recorded master disk **20** is removed from the recording table **66** and flooded with a developer solution to reveal the exposure pattern provided by the master recording system **60**. The amount of dissolution of the data layer **30** in the developer solution is in proportion to the optical energy previously received during the recording process. Further, the amount of dissolution of the data layer **30** in the developer solution is in proportion to development process parameters, including the concentration of the development solution, the development time and temperature. The type of development solution can be similar to development solutions used in conventional recording processes as known to those skilled in the art. As such, by controlling the exposure and development processes, the desired surface relief pattern in the photosensitive material can be achieved. Since the master recording system **60** was controlled to fully dissolve portions of the data layer **30** down to the master substrate **32**, the resulting master grooves (previously shown in FIG. **6**) include master groove bottoms which are defined by the master substrate **32** and, in particular, for recorded track pitches of less than 2 times the mastering spot size. The above master disk process results in master lands having rounded peaks and master grooves having flat, wide and preferably smooth master groove bottoms.

In FIGS. **9–11**, exemplary embodiments are shown illustrating the surface relief pattern or data tracks for master disks **20**A, **20**B, **20**C which have been "overexposed" or "overdeveloped" using the master recording process in accordance with the present invention. With each figure (i.e., FIGS. **9–11**), the amount of exposure/development of data layer **30** has been increased. Referring to FIG. **9**, the master recording/developing process resulted in master lands **34**A defining master grooves **36**A exposed down to master substrate **32**A. Master grooves **36**A have a groove depth of 92 nm with a corresponding flat master groove bottom **42** having a width of 120 nm. Similarly, FIG. **10** illustrates surface relief pattern or data tracks **22**B having master lands **34**B which define master grooves **36**B down to master substrate **32**B. The master grooves **36**B have a groove depth of 88 mm and a corresponding flat master groove bottom **42** which is 160 mm wide. FIG. **11** illustrates master disk **20**C having master lands **34**C which define master grooves **36**C having master groove bottom **42**C defined by master substrate **32**C. Master groove **36**C has a groove depth of 82 nm and a flat master bottom **42** which is 200 nm wide. The more master disk **20** is overexposed during disk recording process, the greater the erosion of the master lands and wider master groove bottoms are achieved.

In FIG. **12**, a graph illustrating the corresponding relationship between master land width and master groove depth using the master recording process in accordance with the present invention is shown. Using conventional mastering processes, for a given data layer thickness, master groove depth and master groove bottom width are linked and dependent upon each other (see FIG. **4**). Using the mastering process in accordance with the present invention, by selection of the initial thickness of the data layer and expose/development level, one can independently specify land width and groove depth. In other words, master groove depth is not dependent upon master groove bottom width, and master groove bottom width is not dependent upon master groove depth. The two parameters are separable, and by selecting a desired data layer thickness, and controlling exposure and development criteria, a desired design criteria for the master disk may be obtained.

In the exemplary embodiment shown, plots are shown illustrating design criteria achieved by increasing initial photosensitive (data) layer thickness (plot **78**) and/or increasing exposure energy/development of the photosensitive layer (plot **79**). In all examples, a 0.22 micron spot size is assumed. Plot **80** had an initial data layer thickness of 120 nm, plot **82** had an initial data layer thickness of 100 nm, plot **84** had an initial data layer thickness of 80 nm, and plot **86** had an initial data layer thickness of 60 nm. As illustrated, master surface geometries are no longer constrained by the master land width to master groove depth linkage as in conventional mastering processes. By starting with different initial data layer thicknesses and controlling expose development level, any point within the width-depth parameter space may be obtained using the disk mastering process in accordance with the present invention. Whereas FIG. **12** shows how by starting with differing initial photosensitive material thickness that any point in the width-depth parameter space may be obtained, FIGS. **13–18** show corroborating experimental results illustrated by atomic force microscope (AFM) traces of several differing geometries at 0.375 and 0.425 micron track pitch using the disk mastering process in accordance with the present invention.

The master recording process in accordance with the present invention is (preferably) used in a reverse mastering

or inverse stamping process, for creation of replica disks having wide, flat (and smooth) land features at track pitches less than two times the mastering system spot size. In FIG. **19**, a diagram illustrating "groove" orientation of an optical disk substrate (i.e., a replica disk) molded from a first generation stamper, a second generation stamper or a third generation stamper formed from a master disk in accordance with the present invention, is shown. The diagram includes enlarged, partial cross-sections illustrating the orientation of the data tracks of a master disk **90**, first generation stamper **92**, second generation stamper **94**, third generation stamper **96**, replica disk substrate **1**, replica disk substrate **2**, and replica disk substrate **3**. Data tracks are recorded onto the master disk **90**, and have on orientation based on whether a replica disk substrate is molded from a first, second or third generation stamper.

In particular, master disk **90** includes master data layer **104** having master lands **106** and master grooves **108**. First generation stamper **92** includes first generation stamper data layer **110** having first generation stamper lands **112** and first generation stamper grooves **114**. Second generation stamper **94** includes second generation stamper data layer **116** having second generation stamper lands **118** and second generation stamper grooves **120**. Third generation stamper **96** includes third generation stamper data layer **122** having third generation stamper lands **124** and third generation stamper pits **126**. Similarly, replica disk substrate **1** includes substrate **1** data layer **123** having substrate **1** lands **130** and substrate **1** grooves **132**; replica disk substrate **2** includes substrate **2** data layer **134** having substrate **2** lands **136** and substrate **2** grooves **138**; and replica disk substrate **3** includes substrate **3** data layer **140** having substrate **3** lands **142** and substrate grooves **144**.

The orientation of substrate **1**, data layer **128** molded from first generation stamper **92** corresponds to the orientation of the master disk data layer **104**. In particular, the first generation stamper data layer **110** is the inverse of the master disk layer **104**. Similarly, replica disk substrate **1** data layer **128** is the inverse of the first generation stamper data layer **110**.

Second generation stamper **94** data layer **116** is the inverse of the first generation stamper **92** data layer **110**, resulting in replica disk substrate **2** data layer **134** being the inverse of second generation stamper **94** data layer **116** and master disk data layer **104**. Likewise, third generation stamper **96** data layer **122** is the inverse of the second generation stamper **94** data layer **116**. Accordingly, disk substrate **3**, data layer **140** is the inverse of the third generation stamper data layer **122**, and corresponds or has the same orientation as the master disk data layer **104**.

It is recognized that the desired orientation of the master disk data layer **104** is dependent on the desired orientation of the replica disk substrate for its intended use. For the examine of high-density replica disks having track pitches less than two times the mastering system spot size (and air incident media), it is desirable to use a master disk form using the master disk recording process in accordance with the present invention and a second generation stamper process, resulting in a replica disk having wide, flat, smooth lands and deep grooves. Alternatively, for disks read through the substrate, a master disk formed using the master disk recording process in accordance with the present invention may be used in a first generation stamper or third generation stamper process where it is desired to mold a replica disk having flat pits or grooves.

In one preferred embodiment, a master disk made using the master disk recording process in accordance with the present invention is utilized in a second generation disk molding process. Suitable disk molding processes including one suitable second generation disk molding process capable of making multiple optical disk stampers from one master disk is as disclosed in U.S. Pat. No. 6,365,329, the disclosure of which is incorporated herein by reference. The above-referenced patent utilizes a unique disk molding process which includes a photopolymerization step which is non-destructive to either the recorded master, first generation stamper or second generation stamper. This allows many next generations stampers to be made, while maintaining the integrity of the data layer transferred from the previous generation disk. In one embodiment, a portion of a first stamper which defines the data layer is transferred to and becomes part of a second stamper without changing the integrity of the data layer.

Alternatively, other stamper processes may be utilized. For example, in another exemplary embodiment an electroforming pyramiding family process is used. This process involves the electroforming of a "father" stamper or first generation stamper from a master disk formed using the process in accordance with the present invention. The father stamper is cleaned, treated and returned to the nickel bath to plate a "mother" or second generation stamper. This process cycle can be repeated several times, resulting in multiple "mother" stampers or second generation stamper being made from a single father or first generation stamper. The same electroforming process may be repeated using the "mother" stamper to make several "daughter" or third generation stampers from each mother.

In FIG. **20**, a block diagram illustrating a process for making a replica disk using a master disk made in accordance with the present invention is shown at **110**. The master disk is for use in a data storage disk molding process. The data storage disk molding process produces replica disks having a surface relief pattern with replica lands and replica grooves. In the exemplary embodiment shown, the process **110** begins with providing a master substrate **(112)**. The master substrate is at least partially covered with a photosensitive material, which is preferably made of photoresist **(114)**. A surface relief pattern having master lands and master grooves is recorded in the data storage master disk, including the steps of exposing and developing the photosensitive material **(116)**. The exposing and developing of a specified thickness of photosensitive material is controlled to form master grooves extending down to substrate interface between the master substrate and the layer of photosensitive material, such that the width of the master grooves at the substrate interface corresponds to a desired width of the replica lands **(118)**.

The master disk can now be used to make a replica disk in a disk molding process. In particular, a stamper is made from the optical master disk **(120)**. A replica disk is made from the stamper **(122)**. The replica disk is capable of storing high volumes of information. In one application, this invention is particularly useful for recording track pitches that are less than 2 times the master recorder spot size.

In FIG. **21**, a block diagram illustrating one exemplary embodiment of using a master disk in accordance with the present invention in a multiple generation disk molding process is shown at **130**. The master disk is fabricated **(132)** using the unique methods previously described herein. The methods include exposing and developing the data layer down to the master substrate. A first generation stamper is made from the master disk **(134)**. A replica disk may be made from the first generation stamper **(136)**.

Alternatively, a second generation stamper is made from the first generation stamper **(138)**. A replica disk is made

from the second generation stamper (**140**). Further, a third generation stamper can be made from the second generation stamper (**142**). A replica disk can be made from the third generation stamper (**144**).

Photosensitive materials include photopolymers or photoresist, or other materials or material blends having similar photosensitive characteristics. One group of suitable photosensitive material includes standard position type high resolution photoresist commercially available from vendors Shipley, OCG, etc. Other suitable photosensitive materials may become apparent to those skilled in the art after reviewing this disclosure.

Suitable photopolymers for use in forming layers, replication layers, or bonding layers discussed herein, include HDDA (4x6x) polyethylenically unsaturated monomer-hexanediol diacrylate; chemlink 102 (3x) monoethylenically unsaturated monomer-diethylene glycol monoethyl ether acrylate, elvacite 2043 (1x3x) organic polymer-polyethylmethacrylate, and irgacure 651 (0.1x0.2) latent radical initiator-2,2-diamethhoxy-2-phenylacetophenone. Another suitable photopolymer includes HHA (hydantoin hexacryulate) 1x, HDDA (hexanediol diacrylate) 1x, and irgacure 651 (0.1x0.2) latent radical initiator-2,2-dimethyoxy-2phenylacetophenone. Other suitable photopolymers may become apparent to those skilled in the art after reviewing this disclosure.

Numerous characteristics and advantages of the invention have been set forth in the foregoing description. It will be understood, of course, that this disclosure is, and in many respects, only illustrative. Changes can be made in details, particularly in matters of shape, size and arrangement of parts without exceeding the scope of the invention. The invention scope is defined in the language in which the appended claims are expressed.

What is claimed is:

1. A master disk comprising:

a master substrate; and

a layer of photosensitive material covering at least a portion of the mater substrate, the photosensitive material including a surface relief pattern in the form of a track pattern defined by adjacent master lands and master grooves, wherein the master grooves extend down to the master substrate, the master grooves including a master groove bottom and the master lands including a master land top, wherein the master groove bottom is wider than the master land top and a track pitch is less than 425 nanometers.

2. The master disk of claim **1**, wherein the master groove bottom is generally flat.

3. The master disk of claim **1**, wherein the master groove bottom is flat relative to the master land tops.

4. The master disk of claim **1**, wherein the master groove bottom is level with other master groove bottoms associated with the master grooves.

5. The master disk of claim **1**, wherein the master groove bottom is wide and flat relative to the master land tops.

6. The master disk of claim **1**, wherein the master groove bottom includes sharp corners.

7. The master disk of claim **1**, wherein the master grooves include a groove depth which is approximately equal to a thickness of the layer of photosensitive material.

8. The mater disk of claim **1**, wherein the master grooves includes a groove depth which is greater than 50 nanometers.

9. The master disk of claim **1**, wherein a width of the master groove bottom is greater than 100 nanometers.

10. The master disk of claim **9**, wherein the width of the master groove bottom is greater than 250 nanometers.

11. The master disk of claim **9**, wherein a groove depth is greater than 50 nanometers.

12. The master disk of claim **1**, wherein a width of the groove bottom is greater than 25 percent of a pitch of the track pattern.

13. The master disk of claim **12**, wherein the width of the groove bottom is greater than 50 percent of the pitch of the track pattern.

14. The master disk of claim **1**, wherein a width of the groove bottom is greater than 160 nanometers, a groove depth is greater than 80 nanometers and a pitch of the track pattern is less than 400 nanometers.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 6,728,196 B2
APPLICATION NO. : 09/850252
DATED : April 27, 2004
INVENTOR(S) : Jathan D. Edwards

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Column 5

Line 60, "0.425" should read --425--.

Signed and Sealed this

Sixteenth Day of February, 2010

David J. Kappos

David J. Kappos
Director of the United States Patent and Trademark Office