METHOD AND APPARATUS FOR DRYING A SUBSTRATE

Background of the Invention

[0001] This invention relates to a method and apparatus for drying a workpiece such as a substrate used in magnetic disk or integrated circuit manufacturing.

[0002] In many manufacturing processes it is necessary to treat a workpiece with a liquid and then dry the workpiece. For example, during the manufacturing of magnetic disks, one typically performs the following manufacturing steps:

1. First, a nickel-phosphorus layer is plated onto an aluminum substrate;
2. The nickel-phosphorus layer is polished and textured;
3. The substrate is cleaned, rinsed and dried;
4. A series of layers are sputtered onto the substrate, e.g. an underlayer such as sputtered NiP or Cr, a magnetic cobalt alloy, and a protective hydrogenated carbon overcoat. An example of such a process is described in U.S. Patent 6,150,015, issued to Bertero et al. and incorporated herein by reference.

[0003] Immediately prior to sputtering, the substrate is cleaned and then dried. It is very important that when the substrate is dried, there should be no impurities left on its surface.

[0004] Numerous other manufacturing processes require drying a workpiece. For example, during various semiconductor manufacturing process steps, semiconductor wafers are immersed in a liquid and then dried. It is very important that there be no impurities on the surface of these wafers after drying.

[0005] One apparatus for drying semiconductor wafers is discussed in European Patent Application 0 385 536. In the '536 apparatus, a wafer is immersed in a liquid and

then slowly removed from the liquid in the presence of a vapor that aids in the drying process. The cooperation of this vapor and liquid creates the so-called Marangoni effect, which facilitates drying of the wafer. In the '536 apparatus, a "knife-shaped member" pushes the wafer out of a liquid and into a region where the wafer can be dried.

[0006] Another apparatus for drying semiconductor wafers is discussed in U.S. Patent 5,569,330, issued to Schild et al. Schild also teaches a structure that pushes a wafer out of a liquid into a region where the wafer can dry.

[0007] During some prior art drying processes, a wafer is held by a holding structure while it is drying. This leaves the possibility of some contamination or drying marks at the point where the drying wafer is held by the holding structure. One apparatus for dealing with this problem is discussed in U.S. Patent 5,884,640, issued to Fishkin et al. In Fishkin's drying apparatus, instead of pushing a wafer out of a liquid-containing bath, the liquid is drained from the bath. As the liquid level falls with respect to the wafer, the wafer is held at different points so that portions of the wafer are not in mechanical contact with a holding structure while those portions are drying.

[0008] U.S. Patent 4,722,752, issued to Steck, discusses another apparatus for drying wafers. Steck's apparatus contains two support structures capable of lifting wafers out of contact with a liquid. A first structure (comprising bars 34 in Steck Fig. 5) lifts Steck's wafers 24 partially out of contact with a liquid. During this time period, a cassette 25 is immersed in the liquid. Steck then pushes cassette 25 out of his liquid. Eventually, cassette 25 dries and thereafter comes into contact with a dry portion of wafers 24. Steck must allow enough time between the time cassette 25 leaves contact

with the liquid and the time cassette 25 contacts wafers 24 so that cassette 25 can dry. This potentially limits the throughput of Steck's device.

Summary

[0009] A method for drying a workpiece in accordance with the present invention comprises lifting the workpiece out of a liquid bath with a first holding structure until a first portion of the workpiece extends out of the liquid. (At this point in the process, a second portion of the workpiece remains within the liquid.) During this part of the method, the first holding structure is immersed in the liquid, and the portion of the workpiece where the first holding structure contacts the workpiece is immersed in the liquid. The portion of the workpiece extending out of the liquid dries. A second holding structure grabs the dry portion of the workpiece extending out of the liquid, and thereafter lifts the workpiece out of contact with the first holding structure and out of contact with the liquid. (The portion of the second holding structure that lifts the workpiece is dry, and typically, this portion of the second holding structure is never immersed within the liquid. In one embodiment, no portion of the second holding structure is immersed within the liquid.) The second portion of the workpiece then dries. In one embodiment, at no time is a drying portion of the workpiece in contact with a holding structure. Thus, the chance of creating drying marks or contamination on the workpiece is minimized.

[00010] Another advantage of a method in accordance with the invention is that because the second holding structure is never immersed in the liquid, there is no need to wait until the second holding structure dries before it can grab the workpiece. Thus, a

method in accordance with the invention is expected to be more efficient than the above-described Steck method.

[00011] In one embodiment, the workpiece is a substrate used to manufacture a magnetic disk. The workpiece can be a nickel-phosphorus plated aluminum alloy, glass, glass ceramic, or other material. After drying, various layers such as an underlayer, a magnetic layer, and a protective layer are deposited (e.g. by sputtering, CVD, PECVD, or other technique) onto the workpiece. However, the workpiece can be another type of structure as well, e.g. a semiconductor wafer.

[00012] In one embodiment, several (or many) workpieces are dried simultaneously.

[00013] In one embodiment, the workpiece is raised at a first speed during the time that the top of the workpiece breaks the surface of the liquid. The workpiece is raised at a second speed after the top of the workpiece has broken the surface of the liquid. The first speed is slower than the second speed. Also, in one embodiment, the workpiece is raised at a third speed during the time when the bottom of the workpiece breaks the surface of the liquid. The third speed is slower than the second speed. The reason for this is that different portions of the workpiece dry at different rates. By adjusting the speed with which the workpiece is raised to accommodate the drying rate of the different portions of the substrate, the overall speed with which the workpiece is dried is improved.

[00014] The workpiece can be a substrate having a centrally defined opening. In such an embodiment, the workpiece is raised at a fourth speed during the time the top of the centrally defined opening breaks the liquid surface and the time the bottom of the centrally defined opening breaks the liquid surface. The fourth speed is typically slower

than the second speed for reasons stated above. The substrate is raised at a fifth speed after the top of the centrally defined opening breaks the liquid surface but before the bottom of the centrally defined opening breaks the liquid surface. The fifth speed is typically greater than the fourth speed. Optionally, the fifth and second speeds can be equal. The first, third and fourth speeds can also be equal. As mentioned above, the speed with which the substrate is raised is modified to account for the fact that the substrate dries more slowly during the time that the top and bottom of the substrate and the top and bottom of the centrally defined opening break the surface of the liquid.

[00015] In one embodiment, a gas or vapor is provided above the top surface of the liquid to facilitate drying. In one embodiment, this vapor comprises IPA (isopropyl alcohol), but other materials can be used, e.g. acetone. Thus, an embodiment of the invention can employ the above-mentioned Marangoni effect.

Brief Description of the Drawings

[00016] Figs. 1 to 9 illustrate apparatus in accordance with the present invention drying a substrate.

[00017] Fig. 10 illustrates a substrate in plan view.

[00018] Fig. 11 illustrates apparatus in accordance with one embodiment of the invention in a cross section plane that is perpendicular to the plane of Figs. 1 to 9.

Detailed Description

[00019] A method in accordance with one embodiment if the invention is used to dry a workpiece, e.g. a disk-shaped workpiece such as substrate 10 shown in Fig. 1.

Substrate 10 can be a substrate used to manufacture a magnetic disk. In one embodiment, substrate 10 can be an aluminum alloy plated with a nickel-phosphorus alloy. Alternatively, substrate 10 can be formed from another material, e.g. glass or glass-ceramic. Substrate 10 typically has a centrally defined opening 12. As is known in the art, at the conclusion of manufacturing, the disk is mounted on a spindle (not shown), and opening 12 is the location where the disk is attached to this spindle.

[00020] During the manufacturing process, it is desirable to bring substrate 10 into contact with a liquid (e.g. to clean or rinse substrate 10) and then to dry substrate 10. Accordingly, after substrate 10 has been immersed in a first tank containing a liquid (not shown), it is moved to a drying apparatus 13 where it can be dried in such a way as to minimize the likelihood of surface contamination. Apparatus 13 comprises a container 14 containing a tank 15 holding a liquid such as water 16 (Fig. 1). (Water 16 can be deionized water, and can be at a temperature between room temperature and about 60°C. However, other liquids and other temperatures can be used.) As mentioned above, during such a process, it is desirable to dry substrate 10 in a manner that prevents or minimizes drying marks or other contaminant deposits on substrate 10. A method in accordance with the invention promotes that goal.

[00021] Referring to Fig. 1, a shuttle 18 carries substrate 10 to a position such that substrate 10 is over tank 15. As soon as substrate 10 is located over tank 15, a cover 20 is retracted in the direction of arrow A. A first holder 22 is moved upwardly (arrow B) so that holder 22 is in position to hold substrate 10. (In one embodiment, holder 22 moves upwardly at a speed between 1.0 to 20 mm/second.) Arms 18a, 18b of shuttle 18 move outwardly (arrows C, D) to thereby let go of substrate 10. At this point in the process,

substrate 10 is held by first holder 22. (Appropriate delays may be inserted into the robotic manipulation process to ensure that holder 22 is in position before shuttle 18 releases substrate 10.)

[00022] In one embodiment, first holder 22 holds substrate 10 at five contact points 22a-22e. However, in other embodiments, different numbers of contact points can be used.

[00023] First holder 22 then lowers substrate 10 (direction E) into tank 15, thereby immersing substrate 10 in water 16 (see Fig. 2). This lowering can be at a relatively high speed (again, between 1.0 and 20 mm/seconds). Substrate 10 can remain immersed in water 16 for about 10 to 300 seconds. Optionally, during this portion of the process, water 16 can be mechanically agitated to promote a cleaning process. This agitation can be ultrasonic or megasonic. (Megasonic agitation is a very high frequency agitation.) Cover 20 is moved in a direction F to close the compartment 24 in which tank 15 is located.

[00024] Thereafter, first holder 22 begins to raise substrate 10 at a first relatively high velocity (see arrow G in Fig. 3). This first velocity is about 1 to 20 mm/seconds. Shortly before the top surface 10t of substrate 10 breaks the surface 16t of water 16, the velocity of holder 22 slows to a second, slower velocity, e.g. between about 0.2 to 1.0 mm/second. This continues until after the top 10t of substrate 10 passes the top surface 16t of water 16 (Fig. 3). Starting before the raising of substrate 10 and continuing throughout the raising of substrate 10, a vapor comprising IPA is introduced into compartment 24 to facilitate the drying of substrate 10, and to promote the above-described Marangoni effect. In one embodiment, IPA is provided by bubbling nitrogen

through isopropyl alcohol to form an IPA vapor. This vapor is introduced through "showerhead openings" or holes (not shown) in the bottom surface 20b of cover 20.

[00025] After top 10t of substrate 10 passes surface 16t of water 16, the rate at which holder 22 raises substrate 10 is increased to a relatively fast velocity, e.g. between about 1.0 and 20 mm/second. Holder 22 continues to raise substrate 10 at this increased rate until the top 12t of opening 12 is about to pass top surface 16t of water 16. At this time, the rate at which holder 22 raises substrate 10 drops again, e.g. to about 0.2 to 1.0 mm/second. After top 12t of opening 12 passes top 16t of water 16, again, the lifting speed of holder 22 increases to the faster velocity, e.g. between 1.0 and 20 mm/second. This change in the speed at which substrate 10 is raised has the following advantage. The drying rate of portion P2, P4 and P6 of substrate 10 (Fig. 10) is greater than the drying rate of portion P1 and P3 of substrate 10 (located at top 10t of substrate 10 and top 12t of opening 12, respectively). Because the speed at which substrate 10 is raised is varied to accommodate differences in the rate at which the different portions of substrate 10 dry, the overall speed of the drying process is improved.

[00026] The rate at which bottom 12b of opening 12 and the bottom 10b of substrate 10 dry is also less than the drying rate of portions P2, P4 and P6. Therefore the speed at which substrate 10 is raised as portions P5 and P7 of substrate 10 pass the surface 16t of water 16 is also reduced.

[00027] Referring to Fig. 4, after bottom 12b of opening 12 passes top surface 16t of water 16, arms 26a, 26b of a second holder move inwardly (see arrows H and I). The second holder then begins to move upwardly (arrow J in Fig. 5) to lift substrate 10 out of contact with holder 22, and pull substrate 10 out of the bath (Fig. 6). Of importance,

arms 26a, 26b of the second holder are never immersed in water 16 during a process in accordance with the invention. Accordingly, it is unnecessary to wait until the second holder dries before it can grab substrate 10. Thus, a drying method in accordance with the present invention is fast and efficient.

[00028] In one embodiment, arms 26a, 26b are brought inwardly until they reach a stop point. Upon reaching this stop point, arms 26a, 26b are still not in contact with substrate 10. Arms 26a, 26b do not contact substrate 10 until they move upwardly. However, in other embodiments, arms 26a, 26b can contact substrate 10 as soon as they move inwardly.

[00029] Also, in one embodiment, holder 22 is still moving in an upward direction at the time that substrate 10 is handed off to arms 26a, 26b (which are also moving upwardly, but faster than holder 22). In this embodiment, the handoff of substrate 22 to arms 26 is similar to the handoff of a baton in a relay race.

[00030] In one embodiment, holder 22 can remain immersed in water 16 while arms 26 continue to lift substrate 10 out of contact with water 16.

[00031] Referring to Fig. 7, when substrate 10 is entirely within a dry portion of compartment 24, the second holder halts. At this point, water 16 is dumped from tank 15, e.g. into the bottom of container 14. (This dumping can be accomplished fairly quickly, e.g. between 2 and 5 seconds. The water can be dumped to a location 14b at the bottom of container 14.) The flow of the IPA vapor into compartment 24 then stops, and hot nitrogen is then introduced into compartment 24 via one or more nozzles 29. The nitrogen can have a temperature between about 150 to 300° (e.g. 200°C) and can be introduced for a time between about 5 and 120 seconds (e.g. 30 seconds). The nitrogen

ensures that any residual water is removed from substrate 10. Because water is dumped from container 15, there is no chance of splashing during this part of the process.

[00032] In one embodiment, during the entire process, room temperature nitrogen is passed through compartment 24. In other words, this nitrogen is introduced into and vented out of compartment 24 as part of the process gas that facilitates drying. This room temperature nitrogen flow occurs during the entire drying process except a) when the IPA vapor is flowing into compartment 24, or b) when the high temperature nitrogen is flowing into compartment 24.

[00033] After the above-mentioned hot nitrogen introduction is complete, cover 20 opens, i.e. by moving in direction K. The second holder then lifts substrate 10 out of apparatus 13 (see Fig. 8). A second shuttle 30 then moves in a direction L to a position under substrate 10 (Fig. 9). The second holder is then lowered (direction M), thereby handing off substrate 10 to shuttle 30, which then carries substrate 10 in direction N to a next station, e.g. a station where substrate 10 can be placed in a cassette.

[00034] As mentioned above, the first and second holders are able to move up and down at different speeds. In one embodiment, first holder 22 is coupled to a motor (schematically shown as motor 32 in Fig. 11) that moves holder 22 up and down. This motor can be a DC brushless servo motor or a stepper motor. The motor is controlled by an electronic controller such as a CTC controller (not shown), manufactured by Control Technology, Inc. Similarly, the motor (not shown) that controls the vertical motion of the second holder is also a DC brushless servo motor or a stepper motor controlled by the CTC controller. However, other mechanisms (including other types of motors) can be used to move the first and second holders up and down. These motors can be coupled to

the first and second holders by a threaded "lead screw" coupling mechanism. In other words, the first and second holders are mechanically coupled to a threaded lead screw structure that is rotated by the above-mentioned motors to move the first and second holders up and down. Fig. 11 schematically illustrates the manner in which holder 22 can be coupled to the threaded cork-screw drive 40. Drive 40 is rotated by a motor 32. As motor 32 rotates drive 40, a carriage 44, coupled to holder 22, rides up and down on drive 40 to raise and lower holder 20. It should be emphasized that Fig. 11 is merely an exemplary illustration of one manner in which the holders can be moved up and down. The second holder can be similarly mounted on a carriage to be moved up and down.

[00035] In one embodiment, arms 26a, 26b of the second holder are moved in and out by a pneumatic device such as an air cylinder. However, other mechanisms can be used to move arms 26a and 26b in and out.

[00036] Fig. 10 shows substrate 10 in plan view, and shows a first area P1 at top 10t of substrate 10, a second area P2 between top 10t of substrate 10 and top 12t of opening 12, a third area P3 at the top 12t of opening 12, a fourth area P4 between the top 12t and bottom 12b of opening 12, a fifth area P5 at the bottom 12b of opening 12, a sixth area P6 between the bottom 12b of opening 12 and the bottom 10b of substrate 10, and a seventh area P7 at the bottom 10b of substrate 10. As described above, substrate 10 moves relatively slowly when areas P1, P3, P5 and P7 move past the top 16t of water 16. Substrate 10 moves relatively quickly when areas P2, P4 and P6 move past top 16t of water 16. (Substrate 10 can also move relatively quickly before area P1 reaches top 16t of water 16 and after area P7 passes top 16t of water 16. Substrate 10 can also move relatively quickly while it is being lowered into water 16.) Area P1 can be a distance D

between 5 and 10 mm wide centered about top 10t of substrate 10. Similarly, areas P3, P5 and P7 can be a distance D between 5 and 10 mm wide, centered about top 12t, bottom 12b and bottom 10b, respectively. Substrate 10 can be about 95 mm in diameter. However, these dimensions are merely exemplary.

[00037] It should also be noted that in some embodiments, the velocity of substrate 10 when area P1 passes top surface 16t of water 16 is not constant, but rather, can vary. Similarly, in some embodiments, the velocity of substrate 10 when areas P2 to P7 pass top surface 16t of water 16 can also vary. Optionally, the upward velocity of substrate 10 when areas P1, P3, P5 and P7 pass top 16t of water 16 can be the same. Also optionally, the velocity of substrate 10 when areas P2, P4 and P6 pass top surface 16t of water 16 can also be the same. In other embodiments, however, they can be different.

[00038] While the invention has been described with respect to specific embodiments, those skilled in the art will recognize that changes can be made in form and detail without departing from the spirit and scope of the invention. For example, different types of workpieces can be rinsed and dried in accordance with the invention. The speeds and timing parameters of the workpieces and the various lifting mechanisms, and other parameters such as temperatures or gas and liquid compositions described herein are exemplary, and other parameters can be used. Although the drawings only show one substrate 10 being rinsed and dried, typically, several or many (e.g. fifty) substrates are rinsed and dried simultaneously. The various holders and shuttles extend lengthwise along an axis perpendicular to the plane of the figures as a set of arms. These arms typically include notches for holding numerous substrates.

[00039] Apparatus in accordance with the invention can comprise optical or other types of sensors, or encoders, for communicating to a controller the location of various elements of the apparatus. The controller can use this information to control the movement of the various shuttles and holders described herein.

[00040] In one embodiment, during the entire time that tank 15 is filled with water 16, an excess amount of water is always slowly introduced into tank 15, and always slowly spills over the top 15t of tank 15. It is believed that if there is any contamination in water 16, it will reside close to top 16t of water 16. Thus, by causing water to constantly overflow tank 15, it is believed that any contamination will constantly be flushed from apparatus 13.

[00041] While the above-described embodiment comprises holders that raise the workpiece out of liquid, in other embodiments, the liquid is drained from the bath and the workpiece remains stationary. In one embodiment, a drain or pump is provided to remove liquid from the bath at different rates so that top 16t of water 16 moves at varying speeds relative to the workpiece. Thus, while top 16t of water 16 is passing a slow-drying portion of the workpiece, top 16t moves at a relative slow speed compared to the speed at which top 16t moves when top 16t is passing a fast-drying portion of the workpiece.

[00042] Also, in one embodiment, first holder 22 holds the workpiece while top 16t of water 16 falls below a first portion of the workpiece. After this first portion of the workpiece is dry, but while a second portion of the workpiece is immersed in water 16, second holder 26 grasps the dry portion of the workpiece and first holder 22 relinquishes the workpiece. Top 16t of water 16 continues to be removed from the bath and

eventually, no portion of the workpiece is left in contact with water 16. During this embodiment, second holder 26 never contacts water 16.

[00043] In yet another embodiment, both the holders 22, 26 and the top surface 16t of water 16 can move simultaneously.

[00044] It should also be appreciated that different aspects of the invention described herein can be practiced independently of other aspects of the invention. Accordingly, all such changes come within the present invention.

We claim:

1. A method for drying a workpiece comprising the acts of:

providing a workpiece in a liquid, said workpiece being held with a first holder such that said workpiece is immersed in said liquid, said first holder contacting said workpiece at a contact area;

raising said workpiece so that a first portion of said workpiece extends out of said liquid but a second portion of said workpiece remains in said liquid;

causing a second holder to lift said first portion of said workpiece while said second portion is still in said liquid, such that the portion of said second holder that lifts said first portion of said workpiece does not come into contact with said liquid during said method and the entire contact area is immersed in said liquid when said second holder begins to lift said workpiece; and

raising said workpiece out of contact with said liquid with said second holder after said act of causing.

2. Method of claim 1 wherein said providing comprises causing said first holder to lower said workpiece into said liquid, and wherein said first holder is immersed in said liquid after said act of causing said first holder to lower.

3. Method of claim 1 wherein said workpiece is a disk-shaped substrate having an opening therein, said act of raising comprising:

raising said substrate at a first rate prior to the time the top of said substrate extends out of said liquid;

raising said substrate at a second rate lower than said first rate while the top of said substrate breaks the surface of said liquid;

raising said substrate at a third rate faster than said second rate after the top of said substrate has broken the surface of said liquid but before the top of said opening breaks the surface of said liquid;

raising said substrate at a fourth rate slower than said third rate while the top of said opening breaks the surface of said liquid;

raising said substrate at a fifth rate faster than said fourth rate after the top of said opening has broken the surface of said liquid but before the bottom of said opening breaks the surface of said liquid;

raising said substrate at a sixth rate slower than said fifth rate while the bottom of said opening breaks the surface of said liquid;

raising said substrate at a seventh rate faster than said sixth rate after the bottom of said opening has broken the surface of said liquid but before the bottom of said substrate breaks the surface of said liquid; and

raising said substrate at an eighth rate slower than said seventh rate while the bottom of said substrate breaks the surface of said liquid.

4. A method for drying a workpiece, said method comprising the acts of:

providing said workpiece in a liquid;

raising said workpiece to remove said workpiece from said liquid, wherein said raising of said workpiece is accomplished at different velocities as said workpiece leaves said liquid, wherein said workpiece is raised at a first rate while the top of said workpiece

is raised past the surface of said liquid, said workpiece is raised at a second rate during a time period after the top of said workpiece is raised past the surface of said liquid, and said second rate is greater than said first rate.

5. Method of claim 4 wherein said workpiece is raised at a third rate while the bottom of said workpiece is raised past the surface of said liquid, said third rate being slower than said second rate.

6. Method of claim 5 wherein said workpiece has a centrally located opening, said workpiece being raised at a fourth rate while the top of said centrally located opening passes the surface of said liquid, said workpiece being raised at a fifth rate during a time period after the top of said opening has passed the surface of said liquid but before the bottom of said opening has passed the surface of said liquid, said workpiece being raised at a sixth rate while the bottom of said opening passes the surface of said liquid, said fourth and sixth rates being slower than said fifth rate.

7. Method of claim 4 wherein the speed at which said workpiece is raised is slower while a slow-drying portion of said workpiece is being pushed past the surface of said liquid than while a fast-drying portion of said workpiece is being pushed past the surface of said liquid.

8. Method of claim 7 wherein said workpiece is a substrate having a centrally located opening and wherein the top and bottom of the substrate and the top and bottom

of the centrally located openings comprise slow-drying portions of the substrate, and other portions of the substrate are fast-drying.

9. Apparatus comprising:

a container for containing a liquid;

a first holder holding a workpiece in said liquid and then raising said workpiece partially out of said liquid, said first holder contacting said workpiece at a contact area during said act of holding; and

a second holder which is not immersed in said liquid, and which grabs a dry portion of said workpiece after said dry portion of said workpiece extends out of said liquid but while a second portion of said workpiece remains within said liquid and while said contact area is entirely immersed in said liquid, said second holder raising said workpiece entirely out of said liquid.

10. Apparatus of claim 9 wherein said first holder moves up at different speeds during the time that said first holder raises said workpiece, and wherein the second holder moves up at different speeds during the time said second holder raises said workpiece.

11. Apparatus of claim 9 wherein said first holder is immersed in said liquid at the time said second holder grabs said dry portion, and said second holder is never immersed in said liquid.

12. Apparatus comprising:

a container for holding a liquid; and

at least a first holder for holding said workpiece while said workpiece is within said liquid, said first holder raising said workpiece out of said liquid at a plurality of different speeds, wherein said workpiece is raised at a first rate while the top of said workpiece passes the surface of said liquid, said workpiece is raised at a second rate during a time period after the top of said workpiece passes the surface of said liquid, and said second rate is greater than said first rate.

13. Apparatus of claim 12 wherein the speed at which said workpiece is raised out of said liquid accommodates different drying rates of different portions of said workpiece.

14. Apparatus of claim 12 wherein said workpiece is raised at a third rate while the bottom of said workpiece passes the surface of said liquid, wherein said second rate is faster than said third rate.

15. Apparatus of claim 14 wherein said workpiece is a substrate having a central opening therein, said apparatus raising said workpiece at a fourth rate while the top of said central opening passes the surface of said liquid, said workpiece being raised at a fifth rate while the bottom of said opening passes the surface of said liquid, and said workpiece is raised at a sixth rate between the time the top and bottom of said opening passes the surface of said liquid, said sixth rate being greater than said fourth and fifth rates.

16. Apparatus of claim 15 comprising a second holder, wherein said first holder raises said workpiece up until a time after the bottom of said opening passes the surface of said liquid, and the second holder raises said workpiece after the bottom of said opening passes the surface of said liquid.

17. A method for drying a workpiece comprising the acts of:

providing said workpiece in a liquid, said workpiece being held with a first holder such that said workpiece is immersed in said liquid, said first holder contacting said workpiece at a contact area;

causing relative motion between said workpiece and a top surface of said liquid so that a first portion of said workpiece extends out of said liquid but a second portion of said workpiece remains in said liquid while said workpiece is being held by said first holder;

causing a second holder to hold said first portion of said workpiece and said first holder to relinquish holding said workpiece while said second portion of said workpiece is still in said liquid and said contact area is entirely within said liquid, such that the portion of said second holder that holds said first portion of said workpiece does not come into contact with said liquid during said method.

18. A method for drying a workpiece, said method comprising:

providing said workpiece in a liquid;

causing relative motion between said workpiece and a top surface of said liquid so as to take said workpiece out of contact with said liquid, wherein the relative motion of

said workpiece with respect to the top surface of said liquid is accomplished at different velocities as said workpiece is taken out of contact with said liquid, and wherein the relative motion when the top of said workpiece passes the surface of said liquid is at a first velocity, the relative motion during a time period after the top of said workpiece passes the surface of said liquid is at a second velocity, and the second velocity is greater than the first velocity.

19. Method of claims 17 and 18 wherein said liquid is in a container, said workpiece is a substrate and said acts of causing relative motion comprise removing liquid from said container.

20. Method of claims 17 and 18 wherein said liquid is in a container, said workpiece is a substrate and said acts of causing relative motion comprise both removing liquid from said container and raising said workpiece out of said liquid.

21. Apparatus comprising:

a container for containing a liquid;

a first holder holding a workpiece in said liquid, said first holder contacting said workpiece at a contact area;

first means for causing relative motion between said workpiece and the top surface of the liquid, said first means causing said workpiece to extend partially out of said liquid;

a second holder which is not immersed in said liquid, and which grabs a dry portion of said workpiece after said dry portion of said workpiece extends out of said liquid but while a second portion of said workpiece remains within said liquid and said contact area is entirely within said liquid; and

second means for causing relative motion between said workpiece and the top surface of the liquid, said second means causing said workpiece to be entirely out of contact with said liquid.

22. Apparatus of claim 21 wherein said first and second means comprise means for removing liquid from said container to cause relative motion between said workpiece and the top surface of the liquid.

23. Apparatus of claim 21 wherein said first and second means comprise means for removing liquid from said container, means for raising said first holder, and means for raising said second holder.

24 Apparatus comprising:

a container for holding a liquid;

at least a first holder for holding said workpiece while said workpiece is within said liquid; and

means for causing relative motion between the top surface of said liquid and said workpiece at a plurality of different speeds, wherein the relative motion when the top of said workpiece passes the surface of said liquid is at a first velocity, the relative motion

during a time period after the top of said workpiece passes the surface of said liquid is at a second velocity, and the second velocity is greater than the first velocity.

25. Apparatus of claim 24 wherein said means for causing causes relative motion between the top surface of said liquid and said workpiece at a plurality of different speeds while said workpiece extends at least partly within said liquid.

26. Apparatus of claim 25 wherein said means for causing is a holder that raises said workpiece at a plurality of different speeds.

27. Apparatus of claim 25 wherein said means for causing comprises means for removing said liquid from said bath at a plurality of different rates.

28. Apparatus of claim 25 wherein said means for causing comprises means for removing said liquid from said container and means for raising said first holder.

29. Method of claim 18 wherein the workpiece has a centrally located opening, the relative motion when the bottom of said workpiece passes the surface of said liquid is at a third velocity, the relative motion when the top of said opening passes the surface of said liquid is at a fourth velocity, the relative motion after the top of said opening passes the surface of said liquid is at a fifth velocity, the relative motion when the bottom of said opening passes the surface of said liquid is at a sixth velocity, said second and fifth velocities are greater than said third, fourth and sixth velocities.

30. Apparatus of claim 24 wherein the workpiece has a centrally located opening, the relative motion when the bottom of said workpiece passes the surface of said liquid is at a third velocity, the relative motion when the top of said opening passes the surface of said liquid is at a fourth velocity, the relative motion after the top of said opening passes the surface of said liquid is at a fifth velocity, the relative motion when the bottom of said opening passes the surface of said liquid is at a sixth velocity, said second and fifth velocities are greater than said third, fourth and sixth velocities.