

TITLE OF THE INVENTION

HIGH EFFICIENCY PHOTORESIST COATING

FIELD OF THE INVENTION

5 This invention relates to an improved method and apparatus for coating semiconductor substrates with organic photoresist polymers. In particular, this invention relates to an improved method and apparatus for coating semiconductor substrates which provides a more uniform photoresist layer and is much more efficient than are current methods in the use of expensive photoresist solutions.

BACKGROUND OF THE INVENTION

10 The manufacture of integrated circuits involves the transfer of geometric shapes on a mask to the surface of a semiconductor wafer. Thereafter, the semiconductor wafer corresponding to the geometric shapes, or corresponding to the areas between the geometric shapes, is etched away. The transfer of the shapes from the mask to the semiconductor wafer typically involves a lithographic
15 process. This includes applying a solution of a pre-polymer solution to the semiconductor wafer, the pre-polymer being selected to form a radiation-sensitive polymer which reacts when exposed to ultraviolet light, electron beams, x-rays, or ion beams, for example. The solvent in the pre-polymer solution is removed by evaporation, and the resulting polymer film is then baked. The film is exposed to
20 radiation, for example, ultraviolet light, through a photomask supporting the desired geometric patterns. The images in the photosensitive material are then developed by soaking the wafer in a developing solution. The exposed or unexposed areas are removed in the developing process, depending on the nature of the radiation-sensitive material. Thereafter, the wafer is placed in an etching environment which
25 etches away the areas not protected by the radiation-sensitive material. Due to their resistance to the etching process, the radiation sensitive-materials are also known as photoresists, and the term photoresist is used hereinafter to denote the radiation-sensitive polymers and their pre-polymers.

30 The photoresist film thickness required depends on the desired resolution, defect protection, and step coverage. Thicker films provide better adhesion, greater

protection for reactive ion erosion, and improved defect protection. However, thicker films also result in lower resolution because they take longer to expose and develop. Photoresist film thicknesses used in current semiconductor manufacturing may be typically 0.5 to 4 μm thick.

- 5 Thickness uniformity of the photoresist layer is an important criterion in the manufacture of integrated circuits. When the radiation is focused through the mask onto the coating, variations in thickness of the coating prevent the precise focus over the entire surface of the wafer which is required to obtain the sharpness necessary to ensure satisfactory reproduction of the geometric patterns on the semiconductor
- 10 wafer for advanced circuits with line width dimensions approaching 0.25 μm line widths and smaller over a surface. Photoresist film thickness uniformity is required to maintain good transfer of the mask pattern to the photoresist. Uniformity is important to maintain a constant exposure level across the surface of the wafer. Nonuniformities cause position overlay errors when optical steppers attempt to
- 15 sense alignment marks beneath the photoresist film. Nonuniformities also change the reflectivity of a photoresist deposited over an oxide.

The small critical dimensions of microelectronic devices require photoresist coating thickness typically to be uniform to within 10 $\text{\AA}$ (3σ). As the critical dimension decreases further, even better uniformities will be required.

- 20 The high cost of the photoresist pre-polymer solutions makes it desirable to devise methods of improving the efficiency of the coating process so as to minimize the amount of the polymer solution required to coat a substrate.

- Methods which have been used or proposed for coating wafers include dip coating, meniscus coating, spray coating, patch coating, bubble coating, chemical
- 25 vapor deposition, and spin coating. Only a few of these methods produce photoresist films with the thicknesses and uniformities required for semiconductor production. Of these methods, only spin coating has a production rate fast enough to meet the demands of chip manufacturers. One major shortcoming of spin coating, however, is that it can waste as much as 90%, or more, of the photoresist
- 30 applied to the wafer surface.

About one million gallons of photoresist are consumed each year at a cost of several hundred million dollars. As the critical dimension of semiconductor devices becomes smaller, new deep UV photoresists will be used. These new photoresists can cost five or more times the cost of the i-line photoresists used currently.

5 Therefore, a new coating method is needed which wastes less photoresist while producing uniform, defect-free coatings at a rate comparable to that of spin coating.

OBJECTS AND SUMMARY OF THE INVENTION

One object of this invention is to provide an improved wafer coating process and apparatus which provide greater coating uniformity across the entire surface of

10 the wafer.

Another object of the invention is to provide an improved wafer coating process and apparatus which provide coating uniformity with less waste and more efficient use of the photoresist.

In a first aspect the invention provides a method of applying a coating of photoresist to a circular semiconductor wafer, the wafer having a top surface, a

15 center, and an outer edge, the method comprising extruding a ribbon of photoresist, the ribbon having a width bounded by outer and inner sides, the ribbon extruded in a spiral pattern which covers the entire top surface of the wafer.

In a second aspect, the invention provides a method of applying a coating of photoresist to a circular semiconductor wafer, the wafer having a top surface, a

20 center, a diameter, and an outer edge, the method comprising the steps of mounting the wafer on a chuck, the top surface of the wafer aligned horizontally and oriented upward; positioning an extrusion head adjacent to the outer edge of the wafer and above the top surface of the wafer, the extrusion head configured to extrude

25 photoresist out an extrusion slot, the extrusion slot having a length bounded by a first end and a second end, the extrusion head positioned with the extrusion slot aligned radially with respect to the wafer, the first end of the extrusion slot located adjacent to the outer edge of the wafer, and the second end of the extrusion slot outside the outer edge of the wafer; rotating the wafer about its center; extruding a

30 ribbon of photoresist from the extrusion slot, the ribbon having a width bounded by outer and inner sides, the width of the ribbon substantially equal to the length of the

slot; and, while extruding photoresist from the extrusion slot, and maintaining the extrusion slot aligned radially with respect to the wafer, moving the extrusion head radially inward from the outer edge of the wafer toward the center of the wafer until the photoresist covers the entire top surface of the wafer.

5 In a third aspect, the invention provides a method of applying a coating of photoresist to a circular semiconductor wafer, the wafer having a top surface, a center, a diameter, and an outer edge, the method comprising the steps of mounting the wafer on a chuck; positioning an extrusion head at the center of the wafer and above the top surface of the wafer, the extrusion head configured to extrude
10 photoresist out an extrusion slot, the extrusion slot having a length bounded by a first end and a second end, the extrusion head positioned with the extrusion slot aligned radially with respect to the wafer, the second end of the extrusion slot located at the center of the wafer and the first end of the extrusion slot located between the center of the wafer and the outer edge of the wafer; rotating the wafer
15 about its center; extruding a ribbon of photoresist from the extrusion slot, the ribbon having a width substantially equal to the length of the slot; and, while extruding photoresist from the extrusion slot, and maintaining the extrusion slot aligned radially with respect to the wafer, moving the extrusion head radially outward toward the outer edge of the wafer until the second end of the extrusion slot
20 reaches the outer edge of the wafer.

 In a fourth aspect, the invention provides an apparatus for applying a coating of photoresist to a circular semiconductor wafer, the wafer having a top surface, a center, a diameter, and an outer edge, the apparatus comprising means for mounting a wafer with the top surface of the wafer aligned horizontally and oriented
25 upward; an extrusion head positioned adjacent to the outer edge of the wafer and above the top surface of the wafer, the extrusion head configured to extrude photoresist out an extrusion slot, the extrusion slot having a length bounded by a first end and a second end, the extrusion head positioned with the extrusion slot aligned radially with respect to the wafer, the first end of the extrusion slot located
30 adjacent to the outer edge of the wafer, and the second end of the extrusion slot outside the outer edge of the wafer; means for rotating the wafer about its center; means for extruding a ribbon of photoresist from the extrusion slot, the ribbon having

a width substantially equal to the length of the slot; and means for, while extruding photoresist from the extrusion slot, and maintaining the extrusion slot aligned radially with respect to the wafer, moving the extrusion head radially inward toward the center of the wafer until the photoresist covers the entire top surface
5 of the wafer.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 illustrates a static dispense method employed to dispense photoresist
10 on a wafer surface in a spin coating process.

FIG. 2 illustrates a forward radial dynamic dispense method employed to dispense photoresist on a wafer surface in a spin coating process.

FIG. 3 illustrates a reverse radial dynamic dispense method employed to dispense photoresist on a wafer surface in a spin coating process.

FIG. 4 is an assembly drawing of a side view of an extrusion head of the
15 invention.

FIG. 5 is a front view of a front plate of an extrusion head of the invention.

FIG. 6 is a front view of a rear plate of an extrusion head of the invention.

FIG. 7 is a front view of a shim of an extrusion head of the invention.

FIG. 8 is a front view of a shim against a back plate.
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FIG. 9 is a cross sectional view of an assembled extrusion head of the invention.

FIG. 10 is a perspective view of an assembled extrusion head of the invention.

FIG. 11 is a cross sectional view of the lips of an extrusion head with a substrate moving beneath the lips of the extrusion head.

FIGs. 12, 13 and 14 are a front view, top view and rear view, respectively of an extrusion spin coating assembly of the invention.

5 **FIG. 15** is a block diagram of an embodiment of a control system in the extrusion spin coating assembly of the invention.

FIGs. 16, 17, 18 and 19 illustrate the configuration of an extrusion spin coating assembly during several steps of the extrusion spin coating process of the invention.

10 **FIG. 20** is a diagram which illustrates certain parameters of extrusion spin coating motion according to the invention.

FIG. 21 illustrates an extrusion spin coating spiral pattern according to the invention.

DETAILED DESCRIPTION OF THE INVENTION

15 **FIGs. 1, 2 and 3** shows three primary methods currently employed to dispense photoresist on a wafer surface in a spin coating process. The method depicted in **FIG. 1** is referred to as "static dispense." In static dispense, the photoresist is dispensed directly into the center of a stationary wafer 10, producing a circular pool of photoresist 12. Alternatively, the entire surface of the wafer 10 may
20 be flooded with photoresist. Often, the wafer 10 is rotated slowly after a static dispense to begin spreading the photoresist 12 over the wafer 10 surface.

 The methods illustrated in **FIGs. 2 and 3** are referred to as "dynamic dispenses," because the wafer 10 is rotating slowly while the photoresist 14, 16 is dispensed. During forward radial dispense, illustrated in **FIG. 2**, the dispense nozzle
25 20 is initially located at the center of the wafer 10 and moves radially outward as the photoresist 14 is deposited. For reverse radial dispense, illustrated in **FIG. 3**, the dispense nozzle begins at the outer edge of the wafer and moves radially inward. In both **FIGs. 2 and 3** the dispense nozzle 20 is illustrated at the end of travel after

having deposited photoresist on the slowly spinning wafer 10. Both forward and reverse radial dispense produce a spiral pattern 14, 16 of photoresist. The geometry of the spiral 14, 16, i.e. number of turns of the spiral and volume of photoresist per unit length along the spiral, is determined by the angular rotation of the wafer 10, the radial velocity of the nozzle 20 with respect to the wafer 10, and the volumetric flow of the photoresist during the dispense. Dynamic dispenses use less photoresist, but static dispenses produce a more uniform film.

After the photoresist is deposited on the wafer, the wafer is accelerated to create a centrifugal force which spreads the photoresist toward the edge of the wafer. The wafer may be spun at an intermediate speed for a few seconds before being accelerated to the final high-speed spin. When the bulk of the photoresist reaches the edge of the wafer, most of the photoresist is flung off in many tiny droplets. It has been shown that while the acceleration rate does not affect the final film thickness, higher acceleration rates do tend to produce more uniform films.

Once the wafer is spun up to the final high speed, the wafer continues to spin to cause the photoresist to reach the desired thickness. Photoresist continues to flow outward and off the wafer in concentric waves. Simultaneously, the solvent in the photoresist evaporates quickly because of high convection over the wafer surface. As the solvent fraction in the photoresist decreases, the viscosity of the photoresist gradually increases, causing the outward flow of photoresist to diminish until it almost ceases. Subsequent thinning of the photoresist comes almost entirely from solvent evaporation. When the solvent is mostly evaporated, typically after about 30 seconds, spinning is stopped, and the wafer is soft baked at a high temperature to evaporate the remaining solvent from the photoresist.

In each of the dispense methods depicted in FIGs. 1, 2 and 3, the photoresist is dispensed onto the wafer in a thick puddle or ribbon, and must be spread by some means, e.g. slow spin, to spread the photoresist to cover the wafer and to reduce the photoresist to a thin layer. In the method of the invention, the photoresist is applied in a thin uniform layer over the entire surface of the wafer. This eliminates the need for the slow spin step, and requires less photoresist to be deposited on the wafer to achieve the desired final thickness and uniformity.

The method of the invention employs extrusion slot coating to dispense a thin ribbon of photoresist over the entire surface of the wafer. Extrusion slot coating is a member of the class of pre-metered coating methods. With extrusion slot coating, the coating thickness can be controlled by the photoresist dispense rate, the efficiency can be near 100%, and the thickness uniformity is very good.

In extrusion slot coating, the photoresist is extruded onto the wafer through a narrow slot. **FIGs. 4-11** illustrate an embodiment of an extrusion head **30** which may be used in the invention. The extrusion head **30** may also be referred to as an extrusion die. **FIG. 4** shows a side assembly view of the extrusion head **30** which is constructed of a stainless steel U-shaped shim **31** sandwiched between a stainless steel front plate **32** and a stainless steel back plate **33**. **FIGs. 5, 6 and 7** show a front view of the front plate **32**, back plate **33**, and shim **31**, respectively. **FIG. 8** shows a front view of the shim **31** against the back plate **33**. Referring to **FIG. 4**, the front plate **32** and back plate **33** are grounded and polished on their inner edges, facing the shim **31**, to provide good seal with the shim **31** and a smooth surface for extrusion. Photoresist enters the extrusion head **30** through a port **34** in the top of the back plate **33**. The port **34** directs the photoresist through a tube **35** to a flow channel **36** (**FIGs. 4, 6**). The flow channel **36** is as wide as the opening of the "U" **37** of the shim **31** (**FIGs. 7, 8**).

FIG. 9 is a sectional view of the extrusion head **30** illustrated in **FIG. 4**. The void created by the u-shape of the shim **31** leaves a narrow gap **38** between the front plate **32** and back plate **33** through which photoresist can flow. At the base of the extrusion head **30**, the gap **38** continues downward between two narrow "lips" **41, 42** which extend the inner surface of the front plate **32** and back plate **33**.

FIG. 10 is a perspective view of the extrusion head illustrated in **FIG. 4**. The gap **38** extends across the opening of the "U" **37** (**FIGs. 7, 8**) of the shim **31** to form an extrusion slot **39** in the extrusion head **30**.

FIG. 11 is a cross sectional view of the lips **41, 42** of an extrusion head **30** with a substrate **50** moving beneath the extrusion lips **41, 42**. Photoresist is extruded out the slot **39** at the base of the lips **41, 42** onto the top surface **51** of the substrate **50**. The width of the gap **38** between the front plate **32** and rear plate **33**,

indicated as d , is equal to the thickness of the shim 31 (FIGs. 4, 9). The coating gap between the lips 41, 42 and the substrate 50 is filled with a bead 46 of coating fluid coming from the slot 39. When the substrate 50 is moved perpendicular to the slot 39, keeping the coating gap constant, fluid is drawn out of the bead 46 and remains
5 as a thin film on the substrate 50. The width of the extruded film, w (FIGs. 19, 20) is approximately equal to the length of the extrusion slot 39, i.e. the opening of the "U" 37 of the shim 31 (FIGs. 7, 8). The average thickness of the extruded film, h , is

$$h = \frac{Q}{wv}$$

10 where v is the coating speed, and Q is the fluid dispense rate. The menisci 44, 45 at the leading and trailing edges of the coating bead 46 are pinned to the corners of the extrusion head lips 41, 42. The corners of the extrusion head lips 41, 42 should have a radius of curvature less than approximately 50 μm to keep the menisci 44, 45 pinned. The capillary, viscous, and inlet pressures in the coating bead 46 must
15 balance the external pressure to maintain stability in the coating bead 46. A slight vacuum at the leading edge of the coating bead 46 can be used to stabilize the coating bead 46 when coating thinner films or at higher coating speeds. The extrusion head lips 41, 42 are normally of equal length ($G_1 = G_2$) and the extrusion head 30 is perpendicular to the substrate 50. For very thin coatings, however, it is
20 sometimes beneficial to have one of the lips extend beyond the other ($G_1 \neq G_2$) or to have the extrusion head 30 slightly tilted from perpendicular to the substrate 50, thereby tilting the coating slot 39 with respect to the substrate 50.

The description of the extrusion spin coating assembly 100 will be with reference to FIGs. 12, 13 and 14, which illustrate front, top and rear views,
25 respectively, of an extrusion spin coating assembly 100 according to the invention. Components of the extrusion spin coating assembly 100 illustrated in FIGs. 12, 13 and 14 include a coating module 110 and a positioning system 130. Not illustrated in FIGs. 12, 13 and 14, but described with reference to FIG. 15, is a control system 210 which includes a positioning controller 220 and a spinner controller 280.

30 The coating module 110 includes a spinner assembly 111 which includes a spinner servomotor (not illustrated, reference numeral 113 in FIG. 15) connected to

a vertical shaft 112. The vertical shaft 112 supports a Teflon vacuum chuck 114. The spinner assembly 111 can be moved vertically using a chuck elevator servomotor (not illustrated, reference numeral 115 in FIG. 15). The chuck elevator servomotor is equipped with an elevator motor brake (not illustrated, reference numeral 135 in FIG. 15). With the spinner assembly 111 at its lowest position, the chuck 114 is surrounded by a catch cup 116 (sectional view illustrated). The catch cup 116 is a circular cup having an open top 117. The upper portion 120 of the cup wall 118 tilts inward to facilitate retaining waste photoresist within the catch cup 116. The catch cup 116 serves three purposes. The catch cup 116 catches and drains waste photoresist out a liquid waste drain 122. The catch cup has an exhaust vent 118 through which evaporated solvent is removed. The catch cup 116 directs the flow of air over a spinning wafer to avoid turbulence. Both the exhaust vent 118 and waste drain 122 exit the bottom 124 of the catch cup 116. Means for removing waste photoresist and exhausted vapors are well known to those skilled in the art and are therefore not illustrated.

The spinner assembly 111 has a centering device including eight Teflon pins 138 for centering wafers on the chuck 114, and three vertical pins (not illustrated) for supporting loose wafers before and after processing. The centering pins 138 are controlled by a centering solenoid (not illustrated, reference numeral 119 in FIG. 15). Sensors on the coater module 110 indicate chuck 114 vertical home position (not illustrated, reference numeral 121 in FIG. 15), vacuum state (on/off) (not illustrated, reference numeral 123 in FIG. 15), and centering pin position (not illustrated, reference numeral 125 in FIG. 15). These features of the coating module 110 are well known to those skilled in the art and are therefore not illustrated.

A coater module 110 suitable for use with the invention is a 90SE coater module which is commercially available from Silicon Valley Group, Inc. The 90SE coater module is one component of a 90SE Wafer Processing track also commercially available from Silicon Valley Group, Inc.

The positioning system 130 is supported by an aluminum baseplate 132 which is mounted above the coater module 110. The baseplate 132 has a center cut-out 134 positioned over the coater module 110. First and second vertical

support plates 134, 136 mounted above the baseplate support a cross-support 137 on which a two-axis positioning system 150 is mounted. The positioning system 150 includes an x-axis positioning table 152 and a z-axis positioning table 162. The x-axis positioning table 152 includes an x-axis table motor 154 and x-axis table base 156. Likewise, the z-axis positioning table 162 includes a z-axis table motor 164 and z-axis table base 166. The z-axis positioning table 162 also includes a z-axis brake (not illustrated, reference numeral 133 in FIG. 15). The z-axis positioning table 162 is mounted on the carriage 158 of the x-axis positioning table 152. The x-axis positioning table 152 moves in a horizontal plane, parallel to the surface 51 of a wafer 50 mounted on the chuck 114, and the z-axis positioning table 162 moves in a vertical direction perpendicular to the plane of the surface 51 of a wafer 50 mounted on the chuck 114. A positioning system suitable for use in the x-axis and z-axis positioning tables 152, 162 of the invention is the Parker Daedal Motion Table driven by 5-pitch ball screws.

15 An extrusion head 30 is mounted at the bottom of an aluminum extrusion head support 172 which, in turn, is mounted on the z-axis positioning table 162. The z-axis positioning table 162 has sufficient range of motion to move the extrusion head 30 from a position above the base plate 132, down, through the center cut-out 134 in the baseplate 132, to the proximity of a wafer 50 on the chuck 114.

20 An optical sensor 174 is mounted on the extrusion head support 172. The optical sensor 174 is used to measure the gap between the extrusion head 30 and a wafer 50 mounted on the chuck 114. A sensor suitable for use in an embodiment of the invention is a Philtec RC140L reflectance compensated optical displacement sensor. The optical sensor 174 shines a light on the surface of the wafer 50, measures the reflected light, and generates a voltage proportional to the intensity of the measured light. The spot size of the Philtec sensor is 6mm and has a bandwidth from DC to 100 Hz. The voltage-distance curve of the Philtec sensor is generally non-linear, but has a linear region when the sensor-wafer distance is between, for example, 5.51 and 6.17 mm (0.217 and 0.243 inch). The optical sensor 174 is positioned on the extrusion head support 172 so that all measurements fall within the linear range of the optical sensor 174.

Means for controlling flow of the photoresist includes a photoresist pump (not illustrated) and a photoresist shutoff valve 129. Such arrangements are well known to those skilled in the art, and therefore is not fully illustrated in FIGs. 12, 13 or 14. However, the following description of the control system 210 of the extrusion spin coating assembly 100 includes reference to the photoresist pump (not illustrated, reference numeral 127 in FIG. 15) and the photoresist shutoff valve 129.

FIG. 15 is a block diagram which illustrates an embodiment of a control system 210 suitable for controlling the extrusion spin coating assembly 100 of the invention. The control system 210 includes a computer 212, a positioning controller 220 and a spinner controller 280. The computer 212 downloads programs to the positioning controller 220, the spinner controller 280 and the photoresist dispense pump 127 via serial interfaces 213, 214, 215. The positioning controller 220 sends commands to the photoresist dispense pump 127 to start and stop photoresist flow and to control the photoresist shutoff valve 129. The positioning controller 220 also controls the position of the x-axis positioning table 152 via the x-axis motor 154 and z-axis positioning table 162 via the z-axis motor 164, and the chuck elevator servomotor 115. The positioning controller 220 receives the output of the optical sensor 174, calculates the distance between the extrusion head 30 and the wafer 50, and uses the results to control the z-axis positioning table 162 via the z-axis motor 164.

A computer suitable for use in the control system 210 is an IBM-compatible PC. Suitable for use as the positioning controller 220 is the Parker Compumotor AT6450 Servo Controller, including the optional ANI analog input PC card and the AUX board. Suitable for use as the spinner controller 280 is The Pacific Scientific SC 755. Although the computer 212, positioning controller 220 and spinner controller 280 are shown separately in the block diagram of FIG. 15, in an embodiment which includes the Parker Compumotor AT6450 and Pacific Scientific SC755 controllers, the Compumotor AT6450 plugs into the motherboard of the PC. The invention also contemplates an embodiment in which both the positioning controller 220 and spinner controller 280 functions are provided by a single, combined controller.

The positioning controller **220** includes a positioning controller processor and several inputs and outputs. The inputs and outputs include a 14-bit analog to digital (A/D) converter, several discrete digital inputs and outputs, and servomotor outputs (the processor and inputs and outputs are well known to those skilled in the art and are not individually illustrated). The output of the optical sensor **174** is coupled to the A/D converter input **224**. The positioning controller **220** discrete digital inputs are optically isolated interfaces, and include a chuck position home indicator input **242** coupled to the chuck position home sensor **121**; a vacuum on/off status indicator input **244** coupled to the vacuum on/off sensor **123** on the vacuum chuck **114**; a centering pin in/out position indicator input **246** coupled to the centering pin position sensor **125**; and one or more manual positioning command inputs **248** coupled to operator manual positioning switches **126**.

The positioning controller **220** outputs include an x-axis servomotor output **226** which is coupled to the x-axis servomotor **154**; a z-axis servomotor output **228** which is coupled to the z-axis servomotor **164**; and an elevator motor output **230** which is coupled to the elevator servomotor **115**.

The positioning controller **220** discrete digital outputs include a photoresist valve on/off output **254** which is coupled to the photoresist shutoff valve **129**; a centering solenoid output **256** which is coupled to the centering solenoid **119** which controls the centering pins **138**; a vacuum solenoid output **258** which is coupled to the vacuum solenoid **131**; a z-axis motor brake output **260** which is coupled to the z-axis brake **133** in the z-axis positioning table **162**; an elevator motor brake output **262** which is coupled to the elevator motor brake **135**; a trigger output **264** to the photoresist dispense pump **127**; and logical outputs **266** to the spinner controller **280**.

The spinner controller **280** runs the coating and spin cycles in response to signals received from the positioning controller **220**. The spinner controller **280** includes a spinner controller processor, a servomotor output, and an encoder (the processor and encoder are well known to those skilled in the art and are not individually illustrated). The spinner controller **280** outputs include a spinner motor output **286** which is coupled to the spinner motor **113**. The output of the spinner

controller 280 also includes a simulated encoder signal 288 which is coupled to the positioning controller. The simulated encoder signal 288 allows electronic gearing of the spinner motor 113 speed to control the x-axis positioning of the extrusion head 30 performed by the positioning controller 220.

5 The extrusion head 30 and the positioning tables 152, 162 must be aligned with respect to a wafer 50 mounted on the chuck 114 to obtain reliable coating. Three alignments are required. These alignments will be described with reference to FIGs. 12, 13 and 14. A first alignment adjusts the path of the extrusion slot 39 so
10 that the extrusion slot 39 passes directly over the center of a wafer 50 mounted on the chuck 114. This alignment is needed to completely cover the center area of the wafer 50. The extrusion head 30 is positioned over the center of the wafer 50 by sliding the vertical support plates 134, 136 forward or backward over the base plate 132. The motion of the vertical support plates 134, 136 is constrained by a guide on the base plate 132. Adjustment bolts at the rear of each of the vertical support
15 plates 134, 136 allow fine tuning of the position of the vertical support plates 134, 136 before the vertical support plates 134, 136 are fastened into place.

 The second alignment adjusts the angle of the x-axis with respect to the wafer surface 51. This alignment maintains a constant gap between the wafer 50 and the extrusion head 30 as the x-axis positioning table 152 changes position. The angle of
20 the x-axis with respect to the wafer surface 51 can be changed by rotating the cross-support 138 about a first pivot 179 at one end of the cross-support 137. Fine and coarse adjustment bolts 184, 186 allow adjustments of the angle between the x-axis and the wafer surface 51 of 1.64×10^{-5} radians per turn of the fine adjustment bolt 184. The angle of the x-axis with respect to the wafer surface 51 can be determined
25 by scanning across the wafer surface 51 with the optical sensor 174. During the scan, with the z-axis fixed, measurements of the optical sensor 174 output and the x-position are recorded. A linear regression of these data pairs provides the angle between the wafer surface 51 and the x-axis.

 The third alignment adjusts the bottom edge of the extrusion head 30, i.e. the
30 extrusion slot 39, until it is parallel with the x-axis and the wafer surface 51. This alignment is crucial for maintaining a constant gap across the width of the extrusion

head 30. The angle between the bottom edge of the extrusion head 30 and the x-axis can be adjusted using a wafer-extruder parallelism adjustment bolt 176. The wafer-extruder parallelism adjustment bolt 176 pivots the extrusion head support 172 about a wafer-extruder parallelism adjustment pivot 178 at the base of the z-axis positioning table 162. The angle between the x-axis and the bottom of the extrusion head 30 can be measured using a linear variable differential transformer (LVDT) sensor. The LVDT sensor is secured to the wafer surface 51 with the measurement tip pointing vertically up. Next, the extrusion head 30 is lowered until the lips 41, 42 of the extrusion head 30 move the LVDT sensor to a reference position. After the x-axis and z-axis positioning table 152, 162 positions are recorded, the procedure is repeated for several other positions along the extrusion head lips 41, 42. The slope of the extrusion head 30 with respect to the x-axis is determined using a linear regression of these data pairs.

The optical sensor 174 may be calibrated in a two-step process. First, a voltage offset (i.e., zero-gap bias) voltage is determined by measuring the output voltage of the optical sensor 174 at several small gap distances using precision shims placed between the extrusion head 30 and the wafer surface 51. A linear regression analysis of the gap distance and sensor voltage data is used to calculate the voltage offset (i.e., sensor voltage at a zero gap). Second, the relationship of the sensor voltage and the height of the extrusion slot 39, in the linear range of the optical sensor 174, is determined by raising the extrusion slot 39 in selected increments (e.g., 10 encoder counts equals 12.7 μm) and recording the sensor voltage at each position. A linear regression of the data pair provides the slope of the curve representing sensor voltage versus z-axis position of the extrusion slot 39. The extrusion head 30 must be aligned with respect to the x-axis and wafer surface, as described above, prior to calibrating the optical sensor 174 so that errors will not arise from the angle between the extrusion head 30 and the wafer surface 51.

The extrusion spin coating process will be described with reference to FIGs. 16 - 19. The alignment and calibration procedures described above may be performed periodically or prior to a series of runs as determined to be necessary based on experience with the equipment used.

Referring to FIG. 16, the vacuum chuck 114 is raised through the cut out 134 in the base plate 132, and the wafer 50 is placed on the chuck 114. The wafer 50 is centered on the chuck 114 using the centering pins 138 (FIG. 13). The chuck vacuum (not illustrated) is turned on to secure the wafer 50. The chuck 114 is lowered, lowering the wafer 50 into the coating position, and the extrusion head 30 is lowered into position at the edge of the wafer 50 with the desired gap between the wafer 50 and the extrusion head lips 41, 42 as illustrated in FIG. 17. The chuck 114 is then rotated at an initial rotational speed which is the desired coating speed. The photoresist shutoff valve 129 is opened and the photoresist pump 127 is triggered to begin dispensing photoresist. The extrusion head 30 is moved radially with respect to the wafer 50. As the extrusion head 30 moves toward the center of the wafer 50, the rotational speed of the chuck 114 is increased and the extrusion head speed is increased at a rate proportional to the increase in the rotational speed in order to maintain the coating speed of the extrusion head 30 over the wafer 50 constant. When the leading edge of the extrusion head 30 reaches the center of the wafer 50, illustrated in FIG. 18, the speed of rotation of the wafer 30 is held constant until the trailing edge of the extrusion head 30 reaches the center of the wafer 50. When the entire wafer 50 is covered with photoresist, the photoresist pump 127 is triggered to stop dispensing photoresist, and the photoresist shutoff valve 129 is closed. Typically, it is necessary to continue extruding photoresist and continue moving the extrusion head 30 until the trailing edge of the extrusion head 30 reaches the center of the wafer 50 in order to cover the entire wafer 50 with photoresist. When the photoresist pump 127 and shutoff valve 129 are triggered to stop dispensing photoresist, a residual amount of photoresist which is already in the extrusion head 30 (and possibly also in tubing leading to the extrusion head 30) may continue to flow and be deposited on the wafer 50. In such cases, the photoresist pump 127 and shutoff valve 129 may be triggered to stop dispensing photoresist a short time prior to covering the entire wafer 50, thereby allowing such residual photoresist to finish covering the wafer 50.

The chuck 114 then lowers the wafer 50 into the catch cup 116, and the extrusion head 30 is raised from the coating area as illustrated in FIG. 19. The wafer 50 is then spun at high speed to remove excess photoresist and achieve the

desired coating uniformity. The chuck 114 stops spinning and is raised through the center cut out 134 in the base plate 132. The vacuum is turned off and the wafer 50 removed from the chuck 114.

FIG. 20 is a diagram which illustrates certain parameters of extrusion spin coating motion according to the invention. In FIG. 20, a wafer 50, has a radius R , and is rotating about its center at an angular velocity of Ω . An extrusion head 30 is above the wafer 50, with the extrusion slot 39 radially aligned with respect to the wafer 50. The extrusion slot 39 has a width w , and is moving radially with respect to the wafer 50 at a velocity u . The distance between the center of the wafer 50 and the trailing edge of the extrusion head 30 is r .

The tangential velocity of any point on the surface of the wafer 50, at a distance r from the axis of rotation shown in FIG. 20 is:

$$v = \Omega r$$

With the trailing edge of the extrusion head 30 at a distance r from the axis of rotation, a spiral extrusion pattern can be made by moving the extrusion head 30 inward one length of the extrusion slot 39 for each revolution of the wafer 50. The extrusion head 30 speed along the diameter of the wafer 50 is then:

$$u = \frac{\Omega w}{2\pi}$$

Solving for Ω and substituting yields:

$$u = \frac{wv}{2\pi r}$$

For radially inward motion, $u = -dr/dt$, and a differential equation for the position of the extrusion head can be obtained as follows:

$$\frac{dr}{dt} = - \frac{wv}{2\pi r}$$

Integrating this equation using the initial condition $r = r_0$ at time $t = 0$ yields:

$$r = \left(r_0^2 - \frac{wvt}{\pi} \right)^{1/2}$$

The wafer rotation speed can be expressed as a function of time as:

$$\Omega = \frac{v}{\left(r_0^2 - \frac{wvt}{\pi} \right)^{1/2}}$$

and the head speed can be expressed as a function of time as:

$$u = \frac{wv}{2\pi \left(r_0^2 - \frac{wvt}{\pi} \right)^{1/2}}$$

FIG. 21 illustrates an extrusion spin coating spiral pattern 202 according to one aspect of the invention. The spiral pattern 202 results from the extrusion head 30 starting at the outer edge 52 of the wafer 50 and moving radially inward toward the center of the wafer 50. A first shaded region 204 represents wasted photoresist at the outer edge of the wafer 50, and a second shaded region 206 represents a double thickness of photoresist extruded in the center region of the wafer 50. It is necessary to start the process with the extrusion head 30 just off the outer edge 52 of the wafer 50 to cover the entire outer edge 52 with the extruded spiral pattern 202 without unnecessary overlap or double thickness around the outer edge 52 of the wafer 50. This results in the first shaded region 204 of wasted photoresist. Likewise, it is necessary to continue to extrude photoresist after the leading edge of the extrusion head 30 reaches the center of the wafer 50 until the entire wafer 50 is covered. Typically, it will be necessary to continue the process until the trailing edge of the extrusion head 30 reaches the center to cover the entire center region of the wafer 50. The overlap in the second shaded region 206 at the center of the wafer 50 is inevitable because of the finite width of the extrusion head 30. However, the amount of wasted and excess photoresist is relatively small, and the efficiency of the extrusion spin coating process far exceeds the efficiency of prior spin coating processes.

FIG. 21 illustrates an extrusion spin coating spiral pattern which results from starting the extrusion head at the outer edge of the wafer and, while spinning the wafer, moving the extrusion head radially inward toward the center of the wafer. The method and apparatus of the invention may instead start the extrusion head at the center of the wafer and move the extrusion head radially outward toward the outer edge of the wafer.

It will be readily apparent to those skilled in the art that this invention is not limited to the embodiments described above. Different configurations and embodiments can be developed without departing from the scope of the invention and are intended to be included within the scope of the claims.



THE INVENTION CLAIMED IS:

1. A method of applying a coating of photoresist to a circular semiconductor wafer, the wafer having a top surface, a center, and an outer edge, the method comprising extruding a ribbon of photoresist, the ribbon having a width, the ribbon extruded in a spiral pattern which covers the entire top surface of the wafer.
2. A method according to Claim 1, wherein the ribbon of photoresist is extruded in a spiral pattern beginning at the outer edge of the wafer and ending at the center of the wafer.
3. A method according to Claim 1, wherein the ribbon of photoresist is extruded in a spiral pattern beginning at the center of the wafer and ending at the outer edge of the wafer.
4. A method according to Claim 1, wherein the width of the photoresist ribbon is between about one tenth and about one third of the diameter of the semiconductor wafer.
5. A method of applying a coating of photoresist to a circular semiconductor wafer, the wafer having a top surface, a center, a diameter, and an outer edge, the method comprising the steps of
 - (a) mounting the wafer on a chuck, the top surface of the wafer aligned horizontally and oriented upward,
 - (b) positioning an extrusion head adjacent to the outer edge of the wafer and above the top surface of the wafer, the extrusion head configured to extrude photoresist out an extrusion slot, the extrusion slot having a length bounded by a first end and a second end, the extrusion head positioned with the extrusion slot aligned radially with respect to the wafer, the first end of the extrusion slot located adjacent to the outer edge of the wafer, and the second end of the extrusion slot outside the outer edge of the wafer,
 - (c) rotating the wafer about its center,
 - (c) extruding a ribbon of photoresist from the extrusion slot, the ribbon having a width which is substantially equal to the length of the slot, and



- 5 (e) while extruding photoresist from the extrusion slot, and maintaining the extrusion slot aligned radially with respect to the wafer, moving the extrusion head radially inward from the outer edge of the wafer toward the center of the wafer until the photoresist covers the entire top surface of the wafer.
6. A method according to Claim 5, wherein the length of the extrusion slot is between about one tenth and about one third of the diameter of the semiconductor wafer.
- 10 7. A method according to Claim 5, wherein the photoresist is extruded from the extrusion slot at a rate which is a constant extrusion rate.
8. A method according to Claim 5, wherein, with the wafer rotating at a rotational speed, and the extrusion head moving at a radial speed, the motion of the radially moving extrusion head with respect to the rotating wafer is at a tangential velocity which is a constant tangential velocity.
- 15 9. A method according to Claim 5, wherein step (e) comprises maintaining the extrusion slot a predetermined distance above the top surface of the wafer.
10. A method according to Claim 9, wherein step (e) comprises determining the distance between the extrusion slot and the top surface of the wafer, and adjusting the position of the extrusion slot to maintain the predetermined distance.
- 20 11. A method according to Claim 10, wherein step (e) comprises determining the distance between the extrusion slot and the top surface of the wafer using an optical sensor.
12. A method according to Claim 5, wherein the photoresist ribbon is extruded in a spiral pattern which covers the entire top surface of the wafer.
- 25 13. A method according to Claim 5, comprising the steps of
- (f) removing the extrusion head, and
 - (g) rotating the wafer at high speed.



14. A method of applying a coating of photoresist to a circular semiconductor wafer, the wafer having a top surface, a center, a diameter, and an outer edge, the method comprising the steps of
- a. mounting the wafer on a chuck,
 - 5 b. positioning an extrusion head at the center of the wafer and above the top surface of the wafer, the extrusion head configured to extrude photoresist out an extrusion slot, the extrusion slot having a length bounded by a first end and a second end, the extrusion head positioned with the extrusion slot aligned radially with respect to the
10 wafer, the first end of the extrusion slot located at the center of the wafer and the second end of the extrusion slot located between the center of the wafer and the outer edge of the wafer,
 - c. rotating the wafer about its center,
 - d. extruding a ribbon of photoresist from the extrusion slot, the ribbon
15 having a width substantially equal to the length of the slot, and
 - e. while extruding photoresist from the extrusion slot, and maintaining the extrusion slot aligned radially with respect to the wafer, moving the extrusion head radially outward toward the outer edge of the wafer until the photoresist covers the entire top surface of the wafer.
- 20 15. An apparatus for applying a coating of photoresist to a circular semiconductor wafer, the wafer having a top surface, a center, a diameter, and an outer edge, the apparatus comprising
- means for mounting a wafer with the top surface of the wafer aligned horizontally and oriented upward,
 - 25 an extrusion head positioned adjacent to the outer edge of the wafer and above the top surface of the wafer, the extrusion head configured to extrude photoresist out an extrusion slot, the extrusion slot having a length bounded by a first end and a second end, the extrusion head positioned with the extrusion
30 slot aligned radially with respect to the wafer, the first end of the extrusion slot located adjacent to the outer edge of the wafer,



- and the second end of the extrusion slot outside the outer edge of the wafer,
means for rotating the wafer about its center,
means for extruding a ribbon of photoresist from the extrusion slot, the
5 ribbon having a width substantially equal to the length of the slot, and
means for, while extruding photoresist from the extrusion slot, and maintaining the extrusion slot aligned radially with respect to the wafer, moving the extrusion head radially inward toward
10 the center of the wafer until the photoresist covers the entire top surface of the wafer.
16. An apparatus according to Claim 15, comprising means for rotating a wafer at a rotational speed, and moving the extrusion head at a radial speed, such that the motion of the radially moving extrusion head with respect to the rotating
15 wafer is at a tangential velocity which is a constant tangential velocity.
17. An apparatus according to Claim 15, comprising means for maintaining the extrusion slot a predetermined distance above the top surface of the wafer.
18. An apparatus according to Claim 17, wherein the means for maintaining the extrusion slot a predetermined distance above the top surface of the wafer
20 comprises means for determining the distance between the extrusion slot and the top surface of the wafer, and means for adjusting the position of the extrusion slot to maintain the predetermined distance.
19. An apparatus according to Claim 18, wherein the means for measuring the distance between the extrusion slot and the top surface of the wafer
25 comprises an optical sensor.
20. An apparatus according to Claim 15, comprising means for extruding a ribbon of photoresist in a spiral pattern beginning at the center of the wafer and ending at the outer edge of the wafer.



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21. An apparatus according to Claim 15, wherein the width of the extrusion slot is between about one tenth and about one third of the diameter of the semiconductor wafer.