

Title: Improvements in and relating to grinding machines

This invention concerns grinding machines and methods of grinding for grinding discs such as wafers of silicon for use in the construction of semi-conductor devices and discs of glass or other brittle materials on which magnetic material is to be deposited for form magnetic memory discs for computer disc drives and the like.

Background to the invention

When grinding discs for either of the above purposes, it is important that the outside diameter of the disc is ground to a high level of accuracy and often to a particular cross-sectional form. In the case of memory disc a circular opening is also required again to an accurately controlled diameter and circularity. In the case of silicon wafers, registration in later manufacturing steps requires registration devices to be formed around the periphery of the disc to be formed around the periphery of the disc such as the formation of flats and notches.

Conventionally edge grinding machines have incorporated linear slideways for all axes. Whether incorporating re-circulating rolling element bearings or air bearings, all such axes share a common failing when grinding brittle material such as discs as aforesaid, namely they permit significant relative motion between grinding wheel and component. This arises from the need to provide for orthogonal movements of grinding wheels usually obtained by stacking one linear axis above another. This motion requires the use of hard wearing grinding wheels to minimise loss of form due to wear, but such wheels tend to produce poor quality surfaces with deep damage.

When grinding silicon wafers, the depth of sub-surface damage

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arising during grinding should be minimised since to be used in subsequent manufacturing steps, a wafer must be delivered with zero damage. When sub-surface damage has arisen, this means post grinding steps of acid etching and polishing. Both processes are expensive. The lesser the damage the shorter the polishing time needed.

Summary of the invention

According to one aspect of the present invention, a grinding machine as aforesaid comprises a rigid platform on which a workhead spindle and a grinding wheel spindle are located and wherein the grinding wheel spindle is itself mounted on a sub-assembly which is attached to the platform by means of flexures which permit limited movement of the sub-assembly parallel to the direction of advance of the grinding wheel spindle to achieve grinding of a workpiece mounted on the workhead spindle, the flexures being such as to inhibit movement of the grinding wheel spindle sub-assembly in all other directions.

Where two grinding wheels are to be mounted on the platform, each is preferably independently mounted on a sub-assembly and each sub-assembly is attached to the platform by flexures as aforesaid.

In a preferred arrangement the platform is itself mounted through vibration absorbing means to a fixed machine base.

According to another aspect of the present invention, each sub-assembly is movable to advance or retract the grinding wheel spindle towards and away from a workhead spindle by cam means.

The cam means may operate in one sense only in which event return spring means may be provided for providing a restoring force in the opposite sense.

Alternatively the cam means may operate in both senses so that

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positive drive is provided to both advance and retract the sub-assembly towards and away from the workhead spindle.

By using cam driven sub-assemblies mounted on flexures attached to a common platform as aforesaid in accordance with the invention, a short stiffness loop is created between grinding wheel and component thereby reducing the risk of relative movement between wheel and component (workpiece) during grinding.

Normally the edge of the disc is formed during the grinding operation so as to create a generally triangular or trapezoidal edge to the disc. In order to achieve this the surface of the grinding wheel is formed in a complementary manner so that as the wheel is engaged with the workpiece component, the complementary form is generated around the edge of the component/workpiece.

The edge profile will only be generated accurately if the complementary form of the grinding wheel does not alter. Clearly as the grinding wheel wears, this profile will change and periodically such wheels have to be re-formed using a suitable forming wheel. Hitherto the initial forming of the grinding wheel complementary profile has been done off machine since hard wearing grinding wheels have had to be used.

By constructing a grinding machine in accordance with the invention, so that the low grinding wheel/component relative motion is exhibited, softer grinding wheels can be used and it has been realised that such wheels can be formed in situ using a suitable forming wheel. A grinding machine constructed in accordance with the invention preferably includes a forming wheel which is mounted so as to be capable of being engaged with the main grinding wheel to allow the latter to be reformed as required.

Preferably and in accordance with another aspect of the



invention, the forming wheel may be mounted on the workhead spindle, typically to the rear of the workpiece/component support.

According to a particularly preferred feature of the invention, it has been found that by using suitably soft grinding wheels, the latter can be formed and reformed in situ. This obviates problems which can arise when a grinding wheel is initially formed off machine and/or has to be removed to be reformed.

Preferably soft resin bond wheels are employed. Such wheels are found to produce very low sub-surface damage when used to grind edge forms. This aspect of the invention thus lies in the combination of a tight stiffness loop and the use of a relatively compliant resin bonded grinding wheel together with a forming wheel which can be brought into play as and when required. These integers, when combined, produce a high surface finish and low sub-surface damage edge in the disc being ground.

The invention therefore additionally provides a method of grinding the edge of a disc comprising the steps of providing a grinding wheel, providing a forming wheel and moving the grinding wheel and forming wheel into engagement so as to form a groove around the edge of the grinding wheel corresponding in cross-section to the complement of the shape to be formed around a workpiece edge during grinding, engaging the grinding wheel with at least one workpiece and grinding the edge thereof into the desired shape, and after the workpiece has been ground or after a succession of workpieces have been ground, re-engaging the grinding wheel and the forming wheel to re-form the groove in the grinding wheel to correct for wear.

The invention also lies in apparatus for performing the above method comprising a grinding wheel, drive means therefor, a forming wheel and drive means therefor, means for moving the grinding wheel so as to plunge grind the edge of the grinding



wheel to form a groove therein of precise cross-section, means for separating the grinding wheel from the forming wheel, and for moving the grinding wheel into engagement with the edge of a circular workpiece component to edge grind the latter, wherein the forming wheel is mounted on the workpiece spindle for rotation therewith.

Means may be provided for replacing a ground workpiece component with further workpiece components to be ground.

Means may also be provided for detecting wear of the profiling groove in the grinding wheel to interrupt the grinding process.

Means may be provided, responsive thereto, to again re-engage the grinding wheel and forming wheel to reform the grinding profile in the edge of the grinding wheel.

The invention is also applicable to grinding machines which additionally grind registration regions around the periphery of a workpiece component such as a flat or a notch, and in accordance with another feature of the invention, a machine embodying the invention includes a grinding wheel spindle on which a grinding wheel can be mounted for engaging a disc workpiece for forming a flat on the peripheral edge thereof.

According to another feature of the invention, a grinding machine includes a grinding wheel spindle on which a grinding wheel can be mounted for engaging the periphery of a circular workpiece component, for grinding a notch therein.

According to another feature of the invention, the grinding wheel and workpiece spindles are mounted in air bearings.

Preferably the workhead is mounted upon a preloaded slideway driven by servo motors and fitted with a high resolution position encoder.

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The flexures typically comprise stress relieved steel links which are directly jointed to the platform on the one hand and the spindle bearing sub-assemblies on the other.

Preferably in a machine adapted for grinding silicon wafers, inspection means is provided capable of on-line inspection of wafer thickness, diameter and cross-section.

Where a notch is to be formed in the external periphery, the inspection means is preferably adapted to check the notch angle and depth.

Where a flat is to be formed around a periphery, inspection means is preferably adapted to check the flat length and the Y-diameter together with the flat corner radii.

The inspection means may be brought into operation so as to check each wafer or more typically will be brought into play after every n th wafer has been ground.

Optical inspection of wafer is preferably performed with the wafer mounted vertically on a vacuum platen which is rotated.

Optical inspection of wafer diameter, roundness and measurements of notches and flats is preferably performed with the wafer mounted vertically on a rotating platen.

Optical inspection means may be mounted so as to point towards the face of the wafer when so mounted, and means is provided for indexing the platen and wafer so that measurements can be made at a plurality of discrete points and compared with those derived from a reference component or template.

Optical inspection of the edge dimensions and profile of a wafer during grinding is preferably undertaken by an inspection device which is pointed towards the edge to inspect its profile as the wafer rotates. Edge data can be compared with (or



stored and subsequently compared with) a set of measurements taken from the edge of a reference component workpiece. A large number of points around the edge of a workpiece are preferably checked and compared with the target shape and dimension.

According to another aspect of the invention, means may be provided to aim a jet of cleaning fluid at the overhanging lip of a wafer whilst the latter is still being rotated. This prevents grinding swarf from running down the rear of the wafer as it is removed from the support platen.

According to another aspect of the invention, the grinding wheel and workpiece component are contained within a sealed enclosure during grinding and preferably the jet of cleaning fluid is introduced into the enclosure.

Preferably the enclosure is formed from a clear plastics material such as polycarbonate.

Preferably the enclosure is sealed by means of an inflatable sealing ring which extends around the enclosure.

As previously indicated, the machine base may be a single piece fabrication, but where vibration isolation is to be optimised it may comprise a two-part structure with vibration absorbing means between the two parts.

In a two-part structure in which one part is mounted above the other by the vibration isolation (absorbing) means, the upper of the two parts may be a metal fabrication which contains or is at least in part formed from polymer concrete so as to provide a direct, highly damped link between the mountings for the cams which move the spindles and the sub-assemblies and the workhead spindle guideway means.

A grinding process for grinding the edge of a silicon wafer



workpiece may comprise two stages, a first in which a resin bond CBN wheel is advanced to rough grind the workpiece edge and a second stage in which a resin bonded diamond wheel is advanced to finish grind the edge.

In accordance with the invention the method includes the steps of forming and reforming both grinding wheels in situ on the machine by plunge grinding the desired formed in the edge of each grinding wheel using a forming wheel.

Preferably the effect of torsional vibrations of the machine base on the grinding wheel stability is reduced by mounting the grinding wheel carrying sub-assemblies in a central position on the machine base. At that point in the machine base there is preferably included a section of polymer concrete which provides high damping to the sub-assemblies.

Where both internal and external diameters are to be finish ground, a two-stage grinding process may be employed for both internal and external grinding, in which a rough grind using a pre-formed metal bonded wheel precedes a finish grind using a formed CBN resin bonded wheel which is formed and reformed in situ on the machine.

The invention will now be described by way of example, with reference to the accompanying drawings, in which:

Figure 1 is a perspective view not to scale of a grinding machine embodying the invention as viewed from the position normally occupied by an operator;

Figure 2 is a side view again not to scale, of the machine shown in Figure 1, again from the side on which the operator normally stands;

Figure 3 is an end view of the machine shown in Figures 1 and 2;



Figure 4 is a cross-section to a slightly larger scale through the flexure mounted sub-assemblies as viewed end-on in Figure 3;

Figure 5 is an enlarged scale view of two of the flexures visible in Figure 4;

Figure 6 is an enlarged cross-sectional view through the upper right hand end showing the cam drive and follower and the spring loading of the sub-assemblies;

Figure 7 is a side view of the sub-assembly end of the machine shown in Figure 2 to an enlarged scale and partly in section;

Figure 8 is a perspective view of a workpiece loading and unloading mechanism which is adapted to be mounted on the right hand side of the end of the machine shown in Figure 3, part of which is visible in Figure 8;

Figure 9 is an opposite perspective view of the component handling apparatus of Figure 8 which also shows disc inspection apparatus and the right hand end of the machine as shown in Figure 2;

Figure 10 is a perspective view from the opposite end of the disc inspection apparatus shown in Figure 9, to an enlarged scale;

Figure 11 is a view of the monitor screen showing the notch as viewed by camera 234;

Figure 12 is a view of the monitor screen showing a flat in a wafer edge as viewed by camera 234;

Figure 13 is a side view of the rear of the assembly of Figure 10, showing the drive between the motor and vacuum chuck, and also showing where a thickness measuring probe can be



positioned for determining wafer thickness before transferring the wafer to the workhead.

Figure 14 is a side view of a multiple grinding wheel assembly such as may be used in the machine show in Figure 1 et seq;

Figure 15 is a side view of a notch grinding wheel such as may be employed in that machine;

Figure 16 is a side view of a workpiece vacuum chuck and dressing wheel assembly; and

Figure 17 is a side view of a wash station which can also serve as an intermediate wafer store.

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Detailed description of the drawings

Figures 1, 2 and 3 illustrate pictorially part of an overall machine station for edge grinding circular discs (wafers) of silicon or similar material. Workpiece handling inspection and centering facilities also form part of the overall machine but will be described with reference to later views in the drawings.

The machine shown in Figures 1 to 3 comprises a control cabinet 10 from which extends a machine bed 12 which carries a floating platform 14 carried on three vibration absorbing feet, one of which can be seen in Figure 1 at 16 and the second part 18 is mounted centrally before the base region 22 and is shown in dotted outline in Figure 1, and the third can be seen at 20 in Figure 3.

The platform 14 includes an integral support structure or base 22 which carries a workhead 24 which is slidable axially along a slideway 26 mounted on an upper surface of the base 22 and which includes a spindle drive motor 28 and vacuum chuck 30 for carrying wafers to be ground.

Edge grinding is achieved by means of a grinding wheel 32 containing a number of annular grooves such as 34 for engaging the edge of a wafer workpiece designated in Figure 2 at 36.

The grinding wheel spindle (not shown) carried in bearing assembly 38 is rotated by an electric motor 40.

Items 38 and 40 are carried on a support generally designated 42 which is mounted close to the centre line of the platform 14 to one side of a rigid strengthening plate 44 which is bolted through flanges to the platform 14 along its base and is secured at its upper end by bolts through another flange 46 to the machine base 22. The function of the plate 44 is to increase the rigidity of the platform 14 relative to the base

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22 and resist transverse vibrations which might otherwise be introduced.

Equidistant from and on the other side of the plate 44 is a second support 48 which carries a slideway 50 on which is mounted a second spindle drive 52 for a notch grinding spindle. Axial movement of the spindle drive 52 is provided by a drive unit 54 (see Figure 2). The spindle drive 52 can also be used to grind the internal diameter of an annular disc.

The workhead edge grinding and notch grinding spindles are mounted in air bearings and the workhead spindle typically has a speed range of 2 to 1000 revs per minute, the edge grinding spindle typically has a speed range up to 6000 revolutions per minute and the notch grinding spindle speed is typically up to 70,000 revolutions per minute.

On the workhead spindle to the rear of the chuck 30 are mounted forming wheels best seen in Figure 2 at 56 and 58. Indexing the workhead 24 in the direction of the arrow 60 in Figure 2 allows the workpiece disc 36 to be engaged by one of the slots such as 34 in the grinding wheel 32 and further movement in the direction of the arrow 60 allows the disc 36 to clear the end face 62 of the grinding wheel assembly and to allow the forming wheels 56 or 58 to engage in the appropriate grooves in the grinding wheel 32.

Lateral movement of the grinding wheel or notch grinder as required is achieved by tilting the support structures 42 and 48 as appropriate relative to the platform 14. To this end both of the structures 42 and 48 are pivotally attached to the platform 14 near the centre line thereof (as will be described in more detail in relation to later figures) and two stops 64 and 66 respectively (see Figure 3) prevent excessive outward movement.

In accordance with the invention, the pivoting is provided by



means of flexures (as will be described) which allow for pivoting movement about two parallel axes close to the centre line of the platform 14 so that structure 42 can describe a small arc such as denoted by arrow 68 and structure 48 can describe an arc as denoted by reference numeral 70.

Drive means for achieving the pivoting movement will be described with reference to later figures.

Attached to the base 22 is a clear Polycarbonate rectilinear housing 72 through which the grinding wheel spindle protrudes. A large, generally oval opening 74 in the face of the housing 72 allows a similarly shaped closure 76 mounted on the workhead 24 to enter and seal off the opening 74 upon appropriate forward movement of the workhead 24 in the direction of the arrow 60 as aforesaid.

An inflatable ring seal 78 around the closure 76 (or alternatively around the internal lip of the opening 74) provides for a fluid tight seal between the closure 76 and the opening 74.

The housing 72 is slidable relative to the base 22 and bellows seals 80 and 82 are provided between the spindle drives 38 and 52 so that after the seal has been made between the closure 76 and the opening 74, the housing 72 will in fact move axially with the workhead assembly 24. Sufficient clearance is provided to the rear of the bellows to allow the housing 72 to move in a continuing sense in the direction of the arrow 60 to allow for the grooves in the grinding wheel to be formed. Movement in the opposite sense is also accommodated by the bellows 80 and 82 so that the closed housing 72 can also follow the workhead 24 as it moves in an opposite sense to that of arrow 60 to allow for the edge of the disc 36 to be engaged by one of the grinding grooves such as 34.

Coolant fluid is sprayed onto the workpiece through nozzles 84



and 86 and similar nozzles are provided for spraying similar fluid onto the forming wheels when required. An interlock is provided to prevent coolant fluid being jetted unless the housing 72 is closed and sealed by the closure 76.

After a grinding operation has been completed and after a final wash with fluid, the housing 72 can be opened by deflating the edge seal 78 and withdrawing the workhead 24 in a direction opposite to that of arrow 60 to the position shown in Figure 2. The finished workpiece 36 can then be demounted and a fresh workpiece installed.

Wheel forming/dressing

Wheel forming can be performed initially before any workpiece has been mounted, in which case the housing 72 is closed by appropriate movement of the workhead 24 and closure 76 without first mounting a workpiece such as 36 on the chuck 30. Wheel forming is performed by appropriate axial movement of the workhead 24 and lateral movement of support 42, so that each of the grooves in turn, such as groove 34, is engaged by the appropriate forming wheel such as 56 or 58. Coolant fluid is provided during the wheel forming operation.

After initial wheel forming, the assembly may be separated by breaking the seal 78 as before mentioned. After mounting a workpiece 36 the assembly can be closed again and grinding undertaken as before described.

Typically re-forming of the groove is performed during machine downtime after one workpiece has been removed and before a subsequent workpiece has been installed, but in a development of the machine in which edge profile checking of the workpiece 36 is performed in situ on the workhead, it may be advantageous to allow for re-forming with the workpiece in place.



Notching

If a workpiece is to be notched, the support 42 is moved laterally to disengage the wheel from the workpiece and support 48 is moved laterally instead so as to engage the edge of the workpiece 36 by the notching spindle (not shown). After notching, the support 48 is moved in an opposite sense so as to disengage the spindle from the workpiece.

Polishing

In an alternative arrangement, a polishing wheel may be mounted on the wheel spindle as well as the grooved grinding wheels, and by axially shifting the workpiece spindle, so the polishing wheel can be brought into engagement with the edge of the workpiece 36.

A drive for shifting the workhead 24 along the slideway 26 is provided at 88.

As shown in Figure 3, a drainpipe 90 conveys fluid from the housing 72 to a storage tank 92 and a pump (not shown) is provided to recirculate the fluid from the tank. A filter may be provided in the tank or in the line between the tank and the pump.

The control housing 10 includes a television display 94 and keyboard 96 and a hand-held control unit 98 is connected via a flying lead 100 to a connection plug 102. An operator can remove the unit 98 and walk to the machine with the unit 98 in his hand, and by pressing appropriate buttons instigate or arrest operation of the machine. The housing 10 houses a computer based control system for supplying control signals and power to the drives on the machine and for receiving signals from transducers, switching and other position/operation/touch etc signal generating sensors on the machine.



A computer keyboard and display may be used to enter data for initially setting up the machine functions, and for determining the spindle speeds, feed rates, stroke and sequence of events.

Since clean room conditions may be required, the whole machine with the exception of the corner of the control unit containing the computer screen and keyboard, may be housed within an external enclosure. The external enclosure is not shown in the drawings.

The slideway 26 on which the workhead slides, is preloaded, and the workhead is driven by server motors and fitted with a high resolution position coder to provide smooth motion during axis move interpolation.

Grinding infeed is achieved as previously described by tilting the structures 42 or 48 as required to bring the grinding element carried thereon into engagement with the edge of the workpiece 36. Although the movement is not truly linear, but arcuate, this can be accommodated in the control signals generated by the control system housed within the housing 10.

Whilst the jets such as 84 and 86 can be used to supply cutting fluid during grinding, they or other jets may be used to direct jets of cleaning fluid at the overhanging lip of the wafer whilst it is still being rotated but after grinding. This prevents grinding swarf from running down the back face of the wafer as it is removed from the chuck.

Grinding process

Typically edges are ground in a two-stage process using a plunge grind roughing operation and a second plunge grind finish cycle which includes a rapid advance of the grinding wheel until a touch sensor detects contact with the workpiece wafer. The grinding wheel axis position at touchdown is used to monitor wheel wear and to ensure that the material removed



per finish cut cycle is kept constant. Grinding wheelforms are maintained by using metal bonded diamond forming wheels permanently mounted on the workhead chuck. The reforming process can be fully automatic and can be programmed to occur every nth wafer, or whenever the ground edge profile becomes unacceptable (as determined by optical inspection of the disc edge profile) or when the touchdown point indicates excessive wheel wear.

Damping

In order to reduce unwanted vibration and resulting grinding damage to the minimum, the structural components making up the grinding machine are filled at least partially with polymer concrete, particularly sections of the base 22 and the bed 12 and if desired also the platform 14.

Subassembly flexure mounting

Figures 4 and 5 illustrate how the two structures 42 and 48 are mounted for hinging movement to permit wheel infeed. As shown in Figure 4, the inboard edges of the two structures 42 and 48 are connected to the platform 14 by means of flexures (sometimes referred to as strip-hinges) two of which are shown at 102 and 104. A second pair in line with the two shown in Figure 4 are provided towards the other end of the structures 42 and 48 nearer to the machine base 22.

As shown in Figure 5 to an enlarged scale, each flexure comprises a metal plate, a central region of which is necked to form a reduced width section 106 in the case of flexure 102 and 108 in the case of flexure 104.

The thicker upper and lower regions of each plate denoted by 110 and 112 in the case of 102 and 114 and 116 respectively in the case of flexure 104 are bolted by means of bolts such as 118 and 120 in the case of flexure 102 on the one hand to a



flange 122 which forms an integral part of the structure 42 and on the other hand to a metal block 124 itself bolted by means of bolts such as 126 and 128 to the platform 14.

In the same way the flexure 104 is secured to a flange 126 which extends from and forms an integral part of the structure 48.

The metal block 124 is spaced vertically from the flanges 122 and 126 and the necked region 106 and 108 of each of the flexures permits a rocking of the structure 42 or 48 respectively about the necked region 106 and 108 respectively of the flexures supporting the structure from the platform 14.

Whilst the flexures 102 and 104 permit tilting of the structures as denoted by arrows 130 and 132 in Figure 5, they do not readily permit any other movement of the structures 42 and 48 relative to the platform 14 about any other axis. Consequently the coupling of the structures 42 and 48 to the platform 14 is very stiff in all directions except about the hinge axis generated by the reduced section regions 106 108 etc.

Infeed drive to sub-assemblies

Movement of the structures 42 and 48 is achieved by means of a cam and follower arrangement acting between each of the structures and rigid assemblies mounted to the platform 14 and the end of the machine base 22. One such drive is shown in Figure 4 as provided within the structure 42. Here a cam 134 is carried by a shaft 136 itself carried in bearings 138 and 140, and is driven by an electric motor 142 through a torsion rigid coupling 144. A follower 146 carried on a shaft (not shown) is carried in bearings 148 and 150 is mounted to the structure 142.

The drive and bearing assembly containing the cam 134 is



supported within a rigid structural framework generally designated 152 and this is separate and spaced from the rest of the structure 42 so that the latter can move relative to the assembly 152 as dictated by the movement of the cam 134 and follower 146.

The return force is provided by spring means acting between the structure 152 and the structure 42.

The unit 48 is driven in a similar manner by a similar assembly contained in a structure 154 shown generally in the cut-away region of the structure 48 in Figure 4.

For simplicity, detail of the return spring is shown in connection with structure 48 but no attempt has been made to show this in the structure 42. Here a thrust rod 156 is secured by means of a threaded and bolted end 158 to the inboard structural component 160 of the structure 48 and the spring 162 is housed within a cylindrical recess 164 formed in the structure 154. A reduced diameter end region 166 prevents the spring from leaving the chamber 164 and a captive washer 168 at the outboard end of the thrust rod 156 holds the spring captive. Movement of the structure element 48 in the direction of arrow 170 results in compression of the spring which provides a restoring force to return the item 48 to its normal upright position when the camming force is removed.

Figure 6 shows the upper end of the unit 42 to a larger scale and the same reference numerals have been used throughout to denote similar parts.

Cam drive

Figure 7 is a side view of the end of the machine shown partly in section in Figure 4, albeit to a slightly reduced scale. As with the other views, it is shown partly cut-away so as to reveal the cam drive mechanism generally designated 170 which



acts on the structure 48 and is not shown in Figure 4. The captive washer 168 is shown at the side of the drive mechanism.

Figure 7 also shows the two flexure mountings at the base of the unit 48, the outboard one being designated 104 and the inboard one being designated 172.

As previously mentioned each of the cam drive arrangements is carried within a rigid housing 152 and 154 and the latter is more clearly visible in Figure 7 as is the horizontal leg 174 by which it is bolted to a protruding plate from the end of the base 22.

Also visible in Figure 7 is the motor 176 for driving the chuck 178 from which the notch grinding spindle 180 protrudes. The motor 176 is carried within a housing 52 previously described in respect of Figure 1, and the housing 52 slides along a slideway 50 as previously described.

Figure 7 shows the bellows seal 82 attaching the housing 52 sealingly to the opening in the casing 72 through which the motor 176 and spindle protrude.

Workpiece transfer

The handling of circular plate-like wafers of silicon typically 100 200 or 300mm diameter or larger is provided by a robotic handling means shown in Figure 8. This comprises a base 182 and structural framework generally designated 184 extending upwardly therefrom to provide a support for a linear slideway generally designated 186 along which a carriage 188 can slide in the direction of the arrow 190. A second slide 192 protrudes from the housing 188 at right angles to the slideway 186 and a sliding member 194 is adapted to move therealong in the direction of the arrow 196. An arm 198 protrudes from the housing 194 and a drive attached thereto and shown at 200 provides for movement of the arm 198 in the direction of the



arrow 202. Electric power for the drives 200 and the drives in the housing 188 is provided via a multi-way umbilical 204 which is retained in a flexible safety harness 206 attached to the linear track 186.

The lower end of the arm 198 is a vacuum chuck 208 and by suitable manoeuvring of the carriages 188 and 200 and the arm 198, so the vacuum closure 208 can be positioned in front of a wafer 210 which is held upright in a supporting sleeve 212. An empty supporting sleeve at 214 is also shown ready to receive a processed wafer.

The base 182 is positioned close to the machine bed 12 part of which is visible in Figure 8. After a machining operation, the two parts of the housing 72 are separated as previously described with references to Figures 1 to 3, and this leaves the finished workpiece 36 exposed and available to be picked up by the arm 198 and vacuum chuck 208. To this end the transfer mechanism of Figure 8 is operated so as to position the chuck 208 opposite the wafer on the workhead so as to retrieve the finished wafer 36 and transfer this to the empty sleeve 214.

Movement of the carriage 194 further out towards the sleeve 212 positions the chuck 208 in front of an unground workpiece 210, and after picking this up, it can be transferred into the inspection station and thereafter the working environment of the grinding machine for attachment to the vacuum chuck 30 in place of the previous wafer 36, for grinding.

It will be appreciated that a plurality of sleeves or cassettes can be provided on the track 216 and all the workpieces located therein can be removed, centred, ground, inspected and returned thereto in turn.

Where an overall enclosure is provided for the apparatus as previously described, the transfer mechanism including its base



182 is preferably located within the enclosure, and a self closing door in an opening therein, is provided to allow cleaned wafers to be inserted and removed.

Wafer centering

As an intermediate step before and after grinding, (preferably during the grinding of another wafer), each of the wafers is positioned in the inspection apparatus shown in Figures 9 and 10, to enable the centre of the wafer to be determined, and thereby allow it to be accurately positioned on the chuck 30 for grinding, and afterwards to enable the edge profile of the wafer to be inspected after grinding, before it is returned to its storage sleeve.

Workpiece inspection

Figure 9 is an overall view showing where the inspection apparatus sits in relation to the grinding machine and the robotic wafer handling system of Figure 8. As before the same reference numerals are used throughout. The robotic wafer handling system is more fully described in our copending UK Patent Application filed concurrently herewith under our reference C403/W.

The inspection apparatus comprises a stand 218 on which is located a support framework comprised of a base 220 and an upright plate 222. A triangular stiffening plate 224 extends from the rear of the plate 222 and both 222 and 224 are welded to the plate 220 as at 226.

Spaced from vertical edge 228 of the plate 222 is a support bracket 230 and a lamp and projection lens arrangement generally designated 232 is supported at the upper end of the bracket 230. A first camera 234 having a lens 236 is mounted on the plate 222 to view the edge of the disc 238 which is back lit by lamp 232.

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As best seen in Figure 9 a motor 240 is mounted on the rear of the plate 222. The motor drives a vacuum chuck (not visible) on which the disc 238 which is to be inspected is planted by the robotic arm 198 and vacuum chuck 208.

Rotation of the motor 240 rotates the wafer 238. By positioning this so that the edge intersects the field of view of the camera lens 236 electrical signals can be derived from the camera output for feeding via a cable 242 to signal analysis apparatus (not shown) for processing data obtained from the signals.

A second camera 244 is mounted on the support plate edge 228, to view the edge of the disc 238 tangentially, so as to obtain information on the profile of the edge. The disc edge is back lit by lamp 246 and signals from the camera 244 are supplied along cable 248. Power for the lamps 232 and 246 is supplied as required along cables 250 and 252 respectively.

A computer 254 is supplied with signals from the cameras 234 and via cables 242 and 248 and controls the cameras and their lamps 232 and 246 via return signal paths along 242 and 248 and via cables 250 and 252 respectively. The output camera 244 can be displayed on a monitor 256 as required, and the profile of the edge of the wafer 238 is shown at 258 together eg with a computer generated template 260, 262 showing the ideal angle for the sides of the profile.

Workpiece centering

This is achieved using the technique described in our copending application filed concurrently herewith under reference C403/W, using the robotic wafer handling system of Figures 8 to 10 and the signals from camera 234, obtained as the circular wafer is rotated through its field of view.



Display of notches and flats

Figure 11 is a view of the monitor 256, this time set to display the output from camera 234, when a notched wafer is in position on the vacuum chuck (not shown in Figure 10) on which the wafer 238 is mounted, where the wafer has been rotated so that the notch is in the field of view of the camera. The notch is visible at 264 and a computer generated template (shown dotted at 266 and 268) is also shown displayed, superimposed on the picture of the notch, to indicate the required angles for the two sides of the notch. Two additional template lines are displayed at 270 and 272 to show the required radii at the entrance to the notch and a further template line 274 is displayed showing the required radius at the bottom of the notch.

Figure 12 is a similar view of the monitor 256 this time displaying one end of a flat peripheral region of a circular wafer if viewed by the camera 234. Here the display of the wafer is denoted by reference numeral 276 and the flat by 278 and the required radii at the ends of the flat is described by a computer generated template line 280.

Wafer thickness measurement

Figure 13 shows the rear of the assembly of Figure 10 and shows the plate 222 and motor 240 driving a vacuum chuck 284 via a drive 286.

A fluid line 290 with jet 292 serves to deliver a jet of air to clean and dry the edge of the wafer 238 and the flow is controlled by a valve 294.

It is important to know the thickness of the wafer 238 before it is mounted on the vacuum chuck 30 on the workhead (see Figures 1 and 2) so that the axial shift required of the workhead or workspindle to bring the appropriate grinding



groove therein accurately into engagement with the edge of the disc, can be determined by the control system and appropriate drive signals generated for moving the workhead or work spindle the required distance. The thickness is determined using a probe 296 which is carried on a spindle 298 slidable in guides 300, 302 and movable under air pressure via a pipeline 304 into engagement with the face of the wafer 238. The distance travelled from a fixed home position is noted.

By performing the same distance movement measurement without the wafer in place, given the distance from the fixed home position to the face of the chuck 284, and since the wafer 238 is held against that face when in position, the difference between the two distance measurements is equal to the thickness of the wafer.

The distance moved by the probe is sensed by an accurate position sensing encoder and the signals supplied along cable 306 to the computer 254, and the thickness dimension may be displayed on the monitor (if desired).

The computer 254 may form part of the computer based control system in housing 10 (see Figure 1) and/or signals generated by the computer 254 may be supplied to the computer based control system in 10, so that the thickness dimension is available for controlling the axial shift of the workhead or work spindle assembly.

Multiple grinding wheel assembly

In order to save machine downtime, the grinding wheel may be made up of a sandwich of different grinding wheels each dedicated to a particular purpose.

Such a wheel is shown at 308 in Figure 14, in which a sandwich of four wheel sections is shown.

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The primary wheel 310 is a resin bonded CBN wheel having six grinding grooves in its cylindrical surface, one of which is shown at 312. This is the wheel section which is used to grind the edge of a wafer which requires only a little material to be removed before finishing.

Wheel section 314 is a diamond wheel containing three grooves, one denoted by reference 316. This section is used for finish grinding the wafer edge.

It is to be understood that both wheels can have any number of grooves - typically in the range 1-10.

Wheel section 318 is a metal bonded CBN or diamond wheel with a single groove 320, which is an optional wheel which can be used to rough grind a wafer edge before the softer resin bonded wheel 310 is brought into play.

Wheel section 322 is a further optional wheel typically of cerium oxide, which can be used to polish the wafer edge after finishing by wheel section 314, by running the wheel spindle at an appropriate speed.

Notch grinding wheel

Figure 15 shows to an approximately similar scale, a notch grinding wheel 324 mounted at the end of a spindle 326. Its "concave" annular grinding surface is typically diamond plated.

Wheel dressing procedure

As shown in Figure 16, the dressing/forming wheel(s) are mounted on the same spindle as the vacuum chuck 30 to which the workpiece(s)/wafer(s) 36 are to be attached.

Typically the dressing/forming wheel is a two part assembly of:

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(a) a metal bonded diamond wheel 328 for rough grinding grooves in the CBN wheel section 310, of Figure 14, and

(b) a metal bonded diamond wheel 330 which incorporates much smaller diameter grit, and is adapted to finish grind the grooves such as 312 in the CBN wheel section 310 of Figure 14.

CBN grinding wheel such as section 310 in Figure 14 are normally supplied without grooves such as 312, and after mounting a new CBN wheel section 310, the first step is the formation of grooves such as 312 thereon. This is achieved using wheel 328 of Figure 16, and then wheel 330.

After wear has occurred in the grooves in 310, wheel 330 is employed to dress and re-form the grooves as required.

Both forming wheels have access to both grinding wheels. Conventionally, both forming wheels are used to form both the roughing (CBN) grinding wheel and the finishing (diamond) grinding wheel.

Intermediate wafer store

As shown in Figure 17, below the thickness measuring probe location shown in Figure 13, is situated an open top rectilinear housing 332 into which wafers can be lowered by the arm 198.

Extending into the housing is a spindle 334 and vacuum chuck 336 on which wafers can be planted and held, and by which such wafers can be rotated. Drive to the spindle 334 may be obtained for example from the motor 240.

Protruding into the housing 332 is a jet 338 which can be supplied with fluid under pressure such as water or air, and the jet is directed towards the face and edge region of wafers mounted on the chuck. One such wafer is shown at 340. A drain



342 conveys away any surplus fluid.

The housing and vacuum chuck provides a useful parking place for wafers which have been edge ground and are waiting to be placed on the vacuum chuck 284 of the inspection apparatus, for edge profile inspection, or have been inspected and are waiting to be returned to their sleeve such as 214 in Figure 8.

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CLAIMS

1. A method of grinding the edge of a disc using a grinding machine having mounted thereon a grooved grinding wheel, in which the groove is formed in situ using a forming wheel also mounted on the grinding machine.

2. A method as claimed in claim 1, comprising the steps of moving the grinding wheel and forming wheel into engagement so as to form a groove around the edge of the grinding wheel corresponding in cross-section to the complement of the shape to be formed around a workpiece edge during grinding, engaging the grinding wheel with at least one workpiece, grinding the edge thereof into the desired shape, and after the workpiece has been ground or after a succession of workpieces have been ground, re-engaging the grinding wheel and the forming wheel with the grinding wheel remaining in situ, to re-form the groove in the grinding wheel to correct for wear.

3. A method of grinding the edge of a silicon wafer workpiece comprising two stages, a first in which a resin bonded CBN wheel is advanced to rough grind the workpiece edge and a second stage in which a resin bonded diamond wheel is advanced to finish grind the edge.

4. A method as claimed in claim 3, wherein the method includes the further steps of forming and reforming both grinding wheels in situ on the machine by plunge grinding the desired formed around the grinding surface of each grinding wheel using a forming wheel.

5. A grinding machine for performing the method of any of claims 1 to 5, comprising a grinding wheel, drive means therefor, a workhead and workpiece spindle and drive means therefor, a forming wheel and drive means therefor, means for





moving the grinding wheel so as to plunge grind the edge of the grinding wheel to form a groove therein of precise cross-section, means for effecting relative movement between the grinding wheel and the forming wheel to enable the grinding wheel to engage with the edge of a circular workpiece component mounted on the workpiece spindle to edge grind the component, wherein the forming wheel is also mounted on the workpiece spindle for rotation therewith.

6. A grinding machine as claimed in claim 5, further comprising means for demounting and replacing a ground workpiece component with a further workpiece component to be ground.

7. A grinding machine as claimed in claim 5 or 6, further comprising means for detecting wear of the profiling groove in the grinding wheel and adapted to interrupt the grinding process if wear is detected.

8. A grinding machine as claimed in claim 7, further comprising means to re-engage the grinding wheel and forming wheel to reform the grinding profile in the edge of the grinding wheel, in response to the interruption of the grinding process.

9. A grinding machine as claimed in any of claims 5 to 8, adapted additionally to grind a registration region such as a flat around the periphery of a disc workpiece which comprises a further grinding wheel spindle on which a further grinding wheel is mounted, said further wheel being movable to engage a disc workpiece for forming a flat on the peripheral edge thereof as the workpiece is rotated relative thereto.

10. A grinding machine as claimed in any of claims 5 to 9, which comprises a further grinding wheel spindle on which a grinding wheel is mounted for engaging the periphery of a circular workpiece for grinding a notch therein whilst the





workpiece is stationary.

11. A grinding machine as claimed in claim any of claims 5 to 10, wherein optical inspection means is mounted so as to point towards the face of the wafer when the latter is mounted for rotation, and means is provided for indexing the platen and wafer thereon so that measurements can be made at a plurality of discrete rotationally different points and compared with those derived from similar points around a reference component or template.

12. A grinding machine as claimed in any of claims 5 to 11, wherein optical inspection of the edge dimensions and the edge profile of a wafer is undertaken by an inspection device which is pointed tangentially towards the edge as the wafer rotates.

13. A grinding machine as claimed in claim 12, wherein the edge inspection is undertaken while the wafer is mounted on the workhead spindle.

14. A grinding machine as claimed in claim 12, wherein the edge inspection is undertaken while the wafer is mounted on a separate vacuum platen adapted to be rotated.

15. A grinding machine as claimed in claim 13 or 14, wherein edge data obtained during edge inspection is compared with (or stored and subsequently compared with) a set of corresponding measurements taken from the edge of a reference component workpiece.

16. In a method of grinding a disc-like workpiece having both internal and external edges which have to be ground, and wherein both internal and external edges also have to be finish ground, a two-stage grinding process is employed for both internal and external grinding, in which a rough grind using a pre-formed metal bonded wheel precedes a finish grind using a formed CBN resin bonded wheel which is formed and reformed





in situ on the machine.

17. A machine for performing the method of any of claims 1 to 5, wherein there is a short stiffness loop between tool and component thereby reducing the risk of relative movement between tool and component (workpiece) during machining, and the tool is a grinding wheel which is formed with a groove in its external cylindrical surface, the cross-sectional shape of which is the complement of what is to be formed around the edge of a component workpiece by grinding when the wheel is engaged with the workpiece component.

18. A machine as claimed in claim 17, which includes a forming wheel which is mounted so as to be capable of being engaged with the grinding wheel to allow the latter to be formed or reformed as required, without being demounted.

19. A grinding machine as claimed in claim 18, wherein the forming wheel is mounted on the workhead spindle.

20. A grinding machine as claimed in claim 19, wherein the forming wheel is mounted to the rear of a workpiece/component support.

21. A grinding machine as claimed in any of claims 17 to 20, wherein the grinding wheel is a resin bonded wheel.

22. An edge grinding machine comprising a rigid platform on which a workhead spindle and a grinding wheel spindle are located, wherein the grinding wheel spindle is itself mounted on a sub-assembly which is mounted to permit movement thereof parallel to the direction of advance of the grinding wheel spindle to achieve edge grinding of a workpiece mounted on the workhead spindle, but so as to inhibit movement thereof in other directions, wherein the grinding wheel is formed with a groove around its workpiece engaging surface, the cross sectional shape of which is the complement of what is to be





formed around the periphery of a workpiece by grinding when the wheel is engaged with the workpiece periphery, and relative movement between grinding wheel and forming wheel enables engagement of the grinding wheel and forming wheel without the grinding wheel being demounted from its spindle.

23. A grinding machine as claimed in claim 22, wherein the forming wheel is also mounted on the rigid platform.

24. A grinding machine as claimed in claim 23, wherein the forming wheel is mounted on the workhead spindle.

25. A grinding machine as claimed in claim 24, wherein the forming wheel is mounted to the rear of a workpiece/component support.

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