

PATENT SPECIFICATION

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(54) OPTICAL ALIGNMENT AND EXPOSURE APPARATUS

(71) We, KASPER INSTRUMENTS, INC., a corporation organised and existing under the laws of the State of California, United States of America, of 983 Shulman Avenue, Santa Clara, State of California, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

The invention relates to alignment apparatus for aligning a mask with a workpiece having a light-sensitive film to be exposed through the mask.

An object of the invention is to provide an improved optical alignment instrument that may be used in the fabrication of integrated circuits to accurately align a semiconductor wafer and a mask with a minimum of operator fatigue and to expose a photo sensitive film on the wafer through the mask.

According to the invention, there is provided alignment apparatus for aligning a mask with a workpiece having a light-sensitive film to be exposed through the mask, said alignment apparatus comprising a base unit having a first holder for the mask, a second holder for the workpiece, and control apparatus for moving at least one of the holders relative to the other to bring the mask and the workpiece into alignment, said alignment apparatus further comprising an optical unit mounted on the base unit and being characterized in that the optical unit includes an ocular lens system, a rotatable turret having a plurality of positions, at least one objective lens system mounted on the turret for alignment with the ocular lens system in at least one of the turret positions to provide a magnified view of the mask and the workpiece on the first and second holders, and an illumination system including an optical element mounted on the turret for directing light on to the workpiece through the mask in another of the turret positions to expose the light-sensitive film on the workpiece.

For a better understanding of the inven-

tion an example thereof will now be described with reference to the accompanying drawings, in which:—

Figure 1 is a plan of an optical alignment instrument according to one embodiment of this invention;

Figure 2 is a side elevational view showing parts of the instrument broken away for clarity;

Figure 3 is a fragmentary vertical longitudinal sectional view through the turret and objective lens system of Figures 1 and 2;

Figure 4 is a sectional view taken along line 4—4 of Figure 3;

Figure 5 is a simplified diagrammatic view showing the light paths for one of the split field lens systems of Figures 3 and 4;

Figure 6 is a view showing the light paths for the single field lens system of Figures 3 and 4;

Figure 7 is a fragmentary vertical longitudinal sectional view through the forward end of the base unit of Figure 2 and showing the movable mask holder and wafer chuck;

Figure 8 is an enlarged transverse sectional view taken along line 8—8 of Figure 1 and showing the mechanism for moving the mask and wafer holders as a unit;

Figure 9 is an enlarged transverse sectional view taken along line 9—9 of Figure 1 and showing the mechanism for moving the mask and wafer holders relative to one another;

Figure 10 is a sectional view taken along line 10—10 of Figure 7 showing the adjusting mechanism for the wafer chuck holder;

Figure 11 is an enlarged vertical longitudinal sectional view through the wafer vacuum chuck and chuck actuating mechanism of Figure 10; and

Figure 12 is a plan view of the wafer loading and unloading mechanism taken along line 12—12 of Figure 7.

Referring to Figures 1 and 2, there is shown an optical alignment and exposure instrument comprising an optical unit 26 and a base unit 28. Optical unit 26 is pivotally secured to base unit 28 by a rod 30 supported

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by brackets 32 of the optical unit and pivotally carried in aligned V-grooves in brackets 34 of the base unit. Keepers 36 attached to the top of brackets 34 maintain rod 30 in the V-grooves.

Base unit 28 is adapted to carry a semiconductor wafer 38 and a high resolution mask 40 through which a light-sensitive film on the wafer is exposed. Optical unit 26 includes a housing comprising a base 37 having flat bottom with upright side walls 42 and comprising a cover 44 having side walls 48 that extend downwards inside base 37 to prevent light leakage therefrom. A mercury vapor lamp 50 mounted on the bottom of base 37 is adjustably positioned by means of a lever 110 connected to lamp mounting 112 through linkage 114. Locking screw 116 extending from one side of optical unit 26 locks lamp mounting 112 in the desired position. Rod 104 is movably carried by rear wall 42A of base 37 for manually adjusting a concave mirror 102 to properly focus a light beam from lamp 50. This light beam is directed through a tubular lens housing 118 containing one or more lenses 120 to a microscope 52 mounted on cover 44 and thence onto wafer 38. Rods 122 slidably extend through wall 42A for manually adjusting housing 118 along the path of the light beam to properly focus the light beam at wafer 38. Piston rod 128 of a fluid cylinder 126 mounted on the bottom of base 37 is pivotally attached to an arm 130. This arm is attached at its inner end to a filter 124 and is attached at its outer end by a pivot pin 132 to a bifurcated bracket 134 mounted on the bottom of base 37. In the illustrated unpressurized condition of cylinder 126, filter 124 is pivoted downwardly into the path of the light beam from lamp 50 to provide filtered light for illuminating wafer 38 and mask 40 during their alignment as described more fully hereinafter. When cylinder 126 is pressurized, filter 124 is pivoted upwardly out of the path of the light beam to provide unfiltered light for exposure of the light-sensitive film on wafer 38, as also described more fully hereinafter.

Two bearing blocks 54 laterally spaced on opposite sides of the path of the light beam from lamp 50 are attached to the bottom of base member 37. Slides 58 at the forward ends of blocks 54 are attached to flanges 64 of cover 44. Slides 60 at the rear ends of bearing blocks 54 are bolted to forward slides 58 through elongated holes 72 in the bearing blocks. Ball bearings are secured between each bearing block 54 and its associated slides 58 and 60 to facilitate movement of the slides along the bearing blocks and hence vertical movement of cover 44 and attached microscope 52 with respect to base 37. A rotatable knob 100 is threadedly coupled through base member 37 to a carriage mov-

ably supported on the bottom of base 37. An inclined plane cam is mounted on the carriage. A roller cam follower is rotatably supported between the lower edges of slides 58 and beneath the path of the light beam from lamp 50. The cam follower rolls up or down the inclined plane cam depending upon which direction the carriage is moved by rotation of knob 100. Thus, by turning knob 100 in one direction slides 58 and 60 and attached cover 44 are raised and by turning it in the opposite direction they are lowered by reason of their own weight and that of the apparatus carried by cover 44. Microscope 52 is raised and lowered with cover 44 and may therefore be focused by knob 100.

Referring now also to Figures 3 and 4 microscope 52 includes an ocular head 140 with binocular eyepieces 142. Ocular head 140 is mounted on raised forward portion 144 of cover 44. An aperture 146 in cover portion 144 is aligned with ocular head 140 and with transfer lens 152 supported in the optical path between the eyepiece and objective lens systems by a lens retaining ring 150. The objective lens system is carried by a turret 154 mounted for rotation about a vertically extending axis. Cover portion 144 has a central downwardly extending boss 156 and a concentric flange 158. A thrust bearing 160 is provided between the lower face of flange 158 and the upper face of turret 154, and a screw 162 extending through a central aperture in the turret is threadedly attached to boss 156 for rotatably supporting the turret. Turret 154 comprises a turret body 163 attached to a cylindrical-shaped top plate 164. A resiliently biased detent device 168 carried by cover 44 is adapted for engagement with any one of four indentations at quadrature spaced locations on the edge 166 of plate 164 for releasably locking the turret at four angularly related positions.

In Figures 3 and 4 turret 154 is shown in the locked position for which the split field objective lens system 178 described below is operatively aligned with transfer lenses 152. A beam splitting device 182 comprising a right-angle prism having mirror surfaces on its right angle faces and having an upwardly extending apex 188 is located directly beneath lenses 152. Prism 182 is supported by a holder 184 secured to turret body 163. The optical system is focused upon a small diameter focusing wire 189 carried by holder 184 a short distance directly above prism 182. Thus, dust or impurities on the prism surfaces are not in focus. A pair of complementary movable lens retaining blocks 189 and 190 having vertical bores 191 for passing light are slidably mounted in pins 192 extending inwardly from a pair of arms 194 on the turret and are resiliently biased toward each other by springs 196 carried on

the pins between the arms and lens blocks. Rollers 200 mounted on blocks 189 and 190 are urged into engagement with a wedge-shaped adjusting member 202. Movement of member 202 towards the center of turret 154 urges blocks 189 and 190 apart, whereas movement in the opposite direction causes springs 196 to move them together. Separation of the optical axes of split field objective lens system 178 is thereby adjustable. Each lens block 189 or 190 carries an inclined mirror 201 adjacent to its upper end, opposite prism 182, and above its passageways 191 for deflecting light beams travelling up through passageways 191 onto the opposite sides of prism 182. With split field lens system 178 in the operative position, illumination of wafer 38 is provided by passing the light beam from lamp 50 through filter 124. The filtered light beam passes through openings 203 in the outwardly facing sides of blocks 189 and 190 and strikes semitransparent mirrors 204 carried by blocks 189 and 190 in inclined grooves 208 that intersect longitudinal light passages 191 and openings 203. Mirrors deflect a portion of the filtered light beam downwardly through passageways 191 and thence through lens tubes 206 attached to blocks 189 and 190 at the lower end of the passageways, thereby illuminating the mask and wafer therebeneath. Light from the illuminated spaced fields on the mask and wafer passes upwardly through lens tubes 206 and semi-transparent mirrors 204 to mirrors 201. Mirrors 201 deflect the light into the opposite sides of prism 182 from whence it is reflected upwardly through transfer lenses 152 and the lenses of ocular head 140 to binocular eyepiece 142 for viewing by the operator.

With turret 154 rotated 180 degrees from the locked position of Figures 3 and 4 another split field objective lens system 180 is operatively aligned with transfer lenses 152. Except as otherwise described below, lens system 180 is constructed the same as lens system 178 (the principal corresponding elements of both systems being designated by the same reference numerals followed by the letter "A" in the case of lens system 180). Referring now also to Figure 5, white light from tungsten lamps 181 carried within housing 216 at diagonally opposite sides of optical unit 26 passes through transverse openings 247 in the outer walls of blocks 189A and 190A. Semitransparent mirrors 248 mounted in inclined grooves 250 in blocks 189A and 190A to intersect passageways 191A and openings 247 deflect portions of this light downwardly through passageways 191A and thence through lens tubes 206A to illuminate the mask and wafer therebeneath. Light from the illuminated spaced fields on the mask and wafer passes upwardly through lens tubes 206A and semitransparent

mirrors 248 to inclined mirrors 201A. From mirrors 201A it is deflected onto the opposite sides of prisms 182A from whence it is reflected upwardly through transfer lenses 152 and the lenses of the eyepiece lens system for viewing by the operator.

Wedges 202 and 202A are adjusted by finger actuated screws 223 and 223A, respectively. Wedge 202 is formed at the end of a rod 224 slidably mounted in a radial bore 226 formed through turret body 163. Reduced thickness end portions 228 and 230 of rod 224 pass between blocks 189 and 190 and between blocks 189A and 190A, respectively. The upper end of a lever 234 extends into an eye member 232 secured to end portion 230 of rod 224. Lever 234 is pivotally mounted on a pin 236 extending between arms 238 that extend from the turret body. Adjusting screw 223 is threadedly mounted in a tube 240 extending from the turret housing. The lower end of lever 234 extends through a slot 242 in tube 240 and engages the end of screw 223. By turning screw 223 into tube 240, lever 234 is rotated counterclockwise to draw rod 224 and attached wedge 202 toward the center of turret 154 and spread blocks 189 and 190 apart. When screw 223 is turned in the opposite direction, the action of springs 196 on blocks 189 and 190 urges rod 224 and attached wedge 202 away from the center of turret 154. This pivots lever 234 in a clockwise direction to keep it in contact with screw 223. Wedge 202A is attached to one end of a rod 244 slidably extending through an axial bore in rod 224. Wedge 202A extends through a transverse aperture 246 in end portion 230 of rod 224 to engage rollers 200A. An eye member 232A secured to the opposite end of rod 244 engages adjusting screw 223A through a pivotal lever 234A. The inner rod 244 and attached wedge 202A are movable independently of outer rod 224 and attached wedge 202. Adjustment of the optical separation of either split field lens system 178 or 180 therefore has no effect upon the other and is simply and conveniently effected from the front of optical unit 26 by the appropriate adjusting screw 223 or 223A.

Split field lens systems 178 and 180 provide a relatively high magnification of, for example, 180 to 600 diameters to enable precise alignment of the mask and wafer. In operation, turret 154 is first rotated to operatively align a single field row and column objective lens system 174 with transfer lenses 152. In this turret position, as shown in Figure 6, light from one of the lamps 181 enters a side bore 256 and is deflected downwardly by a semitransparent mirror 252 through single field objective lenses mounted in vertical bore 254 to illuminate the mask and wafer therebeneath. Light from the single field on the mask and

wafer passes upwardly through semitransparent mirror 252, transfer lenses 152, and the lenses of the eyepiece lens system for viewing by the operator.

- 5 The light-sensitive film on the wafer is exposed by rotating turret 154 to position mirror 176 in the path of the ultraviolet light beam from lamp 50 and by raising filter 124 to an inoperative position. Mirror 176 deflects the unfiltered ultraviolet light beam from lamp 50 down onto the wafer through the mask. In this turret position none of the light from lamp 50 passes upwardly into the eyepiece lens system. Energization of lamp 15 50 during exposure may be controlled by a timer switch 258 having a dial 260 at front panel 262 for selectively setting the exposure time. Switch 258 automatically opens the lamp circuit at the end of the selected time.

- 20 As shown in Figure 2, one end of a hydraulic cylinder 268 is pivotally attached to a bracket 270 secured to cover 265 of base unit 28. The piston rod 272 of cylinder 268 is pivotally connected to one end of a lever arm 274 having its other end secured to a pivotal shaft 276. A roller 280 at the end of a lever 278 secured to shaft 276 engages the bottom of optical unit 26. Levers 274 and 278 function as a bell crank in raising and lowering optical unit 26 as piston rod 272 is retracted and extended from cylinder 268 under control of a valve and a source of fluid pressure.

- 35 As shown in Figures 2 and 7, a mask holder 266 is pivotally mounted between two spaced blocks 286 secured to a top plate 282 of base unit 28. When optical unit 26 is raised to the inoperative position of Figure 2 from the lowered operative position in which the mask and wafer are viewed through one of the objective lens systems of microscope 52, mask holder 266 may be pivoted to the raised position. A spring biased plunger 285 reciprocally mounted in support 287 serves as a stop for the raised mask holder 266. In its extended position plunger 285 permits mask holder 266 to remain in the raised position only so long as held by the operator. This prevents inadvertent lowering of optical unit 26 onto the raised mask holder.

- 50 Mask 40 is held in position over an aperture 288 in holder 266 by vacuum mounting means including a groove 292 formed in the bottom of holder 266 around aperture 288 and covered by the mask. Groove 292 is serially connected through a passageway in holder 266 and through a line 294 and normally open solenoid operated valve to a vacuum source. A normally open microswitch 300 mounted on support 287 is actuated by raised holder 266 to energize the solenoid of this valve and remove the vacuum from groove 292, thereby releasing the mask from the 65 holder and permitting another mask to be

positioned thereon. A pair of concentric resilient seal rings 304 are positioned in grooves 306 on the lower surface of holder 266 for sealingly engaging top plate 282 when the holder is lowered to the operative position. The area between rings 304 is serially connected through a passageway 308 in holder 266 and through a line 310 to the vacuum source, thereby holding the lowered mask holder tightly against plate 282. Vacuum between rings 304 is released when optical unit 26 is raised to permit raising of holder 266.

Top plate 282 is attached to posts 316 and 318 that are secured to a platform 322. Platform 322 is supported by an intermediate plate 336 on a stationary base plate 324 that is attached to flanges 328 and 330 of cover 265. Cover 265 and attached base plate 324 are supported within a base member 264 on resilient shock absorbing legs 322. Intermediate plate 336 is supported by bearings 338 for reciprocal longitudinal movement in the horizontal Y-direction on base plate 324. Bearings 338 may comprise parallel extending rods secured to plates 324 and 336 to serve as ways between which ball bearings 340 are positioned. (Bearings of the same construction may be employed for reciprocally mounting slides 58 and 60 on bearing blocks 54 in optical unit 26). Platform 322 is mounted for reciprocal transverse movement in the horizontal X-direction on intermediate plate 336 by bearings 338-1 of the same type as bearings 338 but oriented at right angles thereto. Thus, the top plate 282 and attached mask holder 266 that are mounted on platform 322 are movable in any horizontal direction.

A vacuum chuck 312 for holding wafer 38 is mounted beneath mask holder 266 on a platform 346. Platform 346 is mounted on movable platform 322 by an intermediate plate 348. Mutually perpendicular bearing supports 338-2 and 338-3 of the same type as bearing 338 and 338-1 support plate 348 on platform 322 and support platform 346 on plate 348, respectively, for movement in the mutually perpendicular Y and X directions. Thus, vacuum chuck 312 is also movable in any horizontal direction. Rollers 358 mounted along the front and back edges of platform 346 are engaged by brackets 360 attached to intermediate plate 348. This prevents vertical separation of platform 346 and plate 348 while permitting transverse movement of platform 346 across plate 348 on bearings 338-3. Rollers 358A and brackets 360A are similarly used to connect platform 322 and plate 336. Platform 322 is similarly connected to plate 348 by rollers and brackets mounted along the side edges thereof.

A control handle 342 is connected for moving platform 322 for row and column scanning. Releasable locking means 364 that normally locks platform 322 against movement

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is released by actuation of a switch 300 on handle 342 to permit scanning. Locking means 364 comprises a cylinder 366 open at the bottom and resting upon stationary base plate 324. A sleeve 368 extends upwardly from cylinder 366 through a large clearance hole 370 in plate 336 and into a hole 372 in platform 322. Longitudinal slots 374 extending downwardly from the upper end of sleeve 368 permit outward expansion of the sleeve into tight engagement with the walls of hole 372. A piston 376 is reciprocally mounted in cylinder 366. Seal ring 378 at the edge of piston 376 provides fluid-tight engagement between the piston and cylinder 366. Piston rod 380 has an enlarged head 382 for expanding sleeve 368. A vacuum source is serially connected through line 386 and passageway 384 in piston rod 380 to the cylinder area below piston 376. This urges enlarged head 382 of piston rod 380 downward to expand sleeve 368 and lock it to platform 322 while locking cylinder 366 to base plate 324, thereby preventing relative movement between platform 322 and base plate 324. Actuation of switch 390 on handle 342 vents line 386 to the atmosphere. This releases the vacuum in cylinder 366 and permits the cylinder to slide along base 324.

Slotted sleeve 368 is sufficiently resilient to return to its normal unflexed condition, thereby urging piston rod 380 upwardly and providing a sliding fit between sleeve 368 and the walls of hole 372.

As shown in Figure 8, control handle 342 is pivotally attached by ball and socket connection 392 to the upper end of a lever 394. The lower end of lever 394 is pivotally attached by ball and socket connection 396 to a plate 398 attached to cover 265. A large clearance hole 400 in cover 265 permits relatively large pivotal movement of lever 394 in any direction from the vertical. A larger diameter disc 402 at the bottom of handle 342 covers hole 400 in any angular position of lever 394. Lever 394 is attached by ball and socket connection 404 to a bracket 406. An arm 408 of this bracket extends through an aperture 410 in flange 412 of cover 265 and is attached to platform 322. Transverse movement of handle 342 therefore moves platform 322 to the right or left across intermediate plate 336. Longitudinal movement of handle 342 in a direction into or out of the plane of the drawing moves platform 322 and plate 336 together along base plate 324. Thus, by moving handle 342, wafer chuck 312 mounted on platform 346 and mask holder 266 carried on platform 322 are moved as a unit for proper positioning in the microscope field.

Referring now to Figure 9, a cylindrical-shaped housing 426 is attached by screws 428 to the bottom of an arm 420. Arm 420 extends through an aperture 410' in flange

412' of cover 265 and is attached to platform 322. A base plate 430 is secured to the bottom of housing 426. Since arm 420 is attached to platform 322, it is moved with platform 322 by handle 342 and is locked against movement with platform 322 by locking device 364 (Figures 7 and 8). A lever 436 is pivotally attached at its upper end by ball and socket connection 434 to a control handle 350 and is pivotally attached at its lower end by ball and socket connection 438 to a vacuum plate 440. The socket of connection 438 is cylindrical-shaped to permit axial movement of the ball therein when lever 436 is pivoted. A recess 442 in the bottom of vacuum plate 440 provides with the top of base plate 430 a vacuum chamber for releasably securing vacuum plate 440 to base plate 430. This chamber is serially connected through a passageway 444 in base plate 430 and through a line 446 and a solenoid-actuated control valve 464 to a vacuum source. Lever 436 is pivotally attached intermediate its upper and lower ends by ball and socket connection 448 to a vacuum plate 450. Vacuum plate 450 comprises a lower ring section 452 engaging base plate 430, an upper ring section 454 containing the socket of connection 448, and an interconnecting wall 456. This vacuum plate is releasably secured to base plate 430 by an annular groove 458 formed in the bottom of section 452 and serially connected through a passageway 460 in section 452, a line 462, and control valve 464 to the vacuum source. When valve 464 is actuated for connecting line 462 to the vacuum source, line 446 is vented to the atmosphere. Vacuum plate 450 is then secured to base plate 430 whereupon ball and socket 448 comprises the fulcrum of lever 436 and vacuum plate 440 is free to slide along base plate 430. When valve 464 is actuated for connecting line 446 to the vacuum source, line 462 is vented to the atmosphere. Vacuum plate 440 is then secured to base plate 430 whereupon ball and socket 438 comprises the fulcrum of lever 436 and vacuum plate 450 is free to slide along base plate 430. A switch 466 for controlling solenoid-actuated valve 464 is mounted on control handle 350 for ready access without releasing the handle. In the normally open switch position the valve solenoid is deenergized for connecting chamber 442 to the vacuum source and for connecting groove 458 to the atmosphere.

Gimbal 468 has a gimbal ring 470 pivotally connected to a tubular bracket 474 by diagonally opposite pivot pins 476 and another gimbal ring 472 pivotally connected to gimbal ring 470 by pivot pins 478 extending at right angles to pivot pins 476. Lever 436 extends through a central hub 480 of gimbal ring 472. As set screw 481 in hub 480 fixes gimbal ring 472 to lever 436. The intersection

of the axes of pivot pins 476 and 478 is spaced a greater distance along lever 436 from the center of ball and socket 438 than from the center of ball and socket 448. This provides both coarse and fine control of bracket 474. Bracket 474 is attached by screws 484 to an arm 482 positioned for movement in a horizontal plane within an enlarged central aperture 424 in arm 420. Arm 482 extends through aperture 410' in flange 412' and is connected by an upwardly extending link 486 to platform 346. Pivotal movement of lever 436 by actuation of handle 350 therefore moves platform 346 relative to platform 322 along the horizontal X and Y directions. Thus, after control handle 342 has been used to move platform 322 and the mask holder carried thereon into position for viewing a key pattern on the mask, control handle 350 is used to move platform 346 and the wafer chuck carried thereon into position for aligning a corresponding key pattern on the wafer with the mask key pattern. Coarse adjustment of the wafer chuck for bringing the wafer key pattern into approximate alignment with the mask key pattern is provided by moving handle 350 with switch 466 in the released position so that lever 436 is pivoted about ball and socket 438. Fine adjustment is provided by closing switch 466 so that the fulcrum of lever 436 is shifted to ball and socket 448 for increased mechanical advantage. Platform 322 is normally locked in position by locking device 364 (Figure 7) when handle 350 is moved for pivoting lever 436 to move platform 346 and the wafer chuck mounted thereon.

As shown in Figure 7, chuck 312 extends through an aperture 494 in platform 346. A radial flange 496 at the lower end of aperture 494 rotatably supports an annular-shaped chuck holder 498. A plate 500 having an aperture 502 in axial alignment with aperture 494 is secured to the top of platform 346, whereby an annular channel 506 is formed between flange 496 and plate 500. Chuck holder 498 has an outwardly directed radial flange 508 that extends into channel 506. Thrust bearings 510 at the upper and lower faces of flange 508 rotatably support holder 498 on platform 346. As further shown in Figure 10, roller bearings 512-1, 512-2, and 512-3 at the periphery of flange 508 maintain chuck holder 498 in axial alignment with aperture 494. Roller bearings 512-1 and 512-2 are mounted on rods fixedly secured to platform 346, whereas roller bearing 512-3 is carried by a block 514 radially slidable in a groove in platform 346. A spring 516 resiliently biases block 514 toward chuck holder 498 for engaging roller bearing 512-3 with the chuck holder which, in turn, is urged into engagement with roller bearings 512-1 and 512-2. Fine and coarse rotatable adjustment of chuck

holder 498 is provided by rotatable adjusting knob 518 and locking knob 520 at opposite sides of platform 346. Knobs 518 and 520 are fixed to the outer ends of rotatable rods 522 and 524, respectively, which threadedly engage opposite ends of a slide 526. Slide 526 is releasably locked in a groove 528 extending across platform 346 by a locking pin 530 extending through an aperture in the side of the slide. The inner end of rod 524 is beveled for engagement with a beveled end of locking pin 530. When knob 520 is rotated to turn rod 524 into the slide, pin 530 is urged outwardly against the wall of groove 528 to lock the slide in the groove. Rod 522 engages one end of a slidable push rod 532. A head at the other end of push rod 532 engages a ball 534 carried at the end of a pin 536 extending from flange 508 on chuck holder 498. The head of another push rod 538 is resiliently urged into engagement with ball 534 directly opposite rod 532 by a compression spring 540. When rod 522 is rotated into slide 526, chuck holder 498 is rotated counterclockwise by action of push rod 532 on ball 534. When rod 522 is rotated in the opposite direction, chuck holder 498 is rotated clockwise by action of spring biased push rod 538 on ball 534. The threaded connection between rod 522 and slide 526 provides for fine rotatable adjustment of chuck 312. Coarse rotatable adjustment of chuck 312 is provided by turning knob 520 to release locking pin 530. Slide 526, with push rods 522 and 524 carried thereby, is then axially movable for coarse rotatable adjustment of the chuck. Thus, wafer chuck 312 may be coarsely and finely adjusted in a rotary direction about its vertical Z axis for aligning the wafer key pattern with the mask key pattern.

Referring now to Figure 11, chuck holder 498 comprises an upper part 498A having radial flange 508, an intermediate annular section 498B having a radial flange secured to part 498A by screws 542, and a lower part 498C attached to part 498B by screws 544. A cylindrical-shaped wall 546 of part 498C extends upwardly through parts 498B and 498A at a spaced distance therefrom. The upper end of a chamber 548 inside cylindrical wall 546 is closed by a member 550 having a downwardly extending sleeve 552 attached thereto. Sleeve 552 telescopically surrounds wall 546 and is axially slidable therealong. A flange 556 on sleeve 552 limits downward travel of the sleeve. Sleeve 552 is raised by applying compressed air to chamber 548 through line 558 and is lowered under action of gravity by venting chamber 548 to the atmosphere. To facilitate lowering, line 558 may be connected to a source of vacuum.

Wafer chuck 312 includes a chuck plate 560 carried by end member 550. The face of chuck plate 560 includes a plurality of

interconnected radial grooves 562 and is covered by a perforated top plate 564. A downwardly extending central stem 566 of plate 560 has an axial bore 568 that communicates with grooves 562. End member 550 has an axial bore 570 with an outwardly flaring upper end 570A. A sleeve 572 at the lower end of bore 570 is connected by a valve to a vacuum source through fitting 574, tubing 576, passageway 578, and tubing 580. With a vacuum applied to chuck plate 560, wafer 38 is held firmly on the chuck. Actuation of the valve for venting line 580 to the atmosphere frees wafer 38 for movement across the chuck. With the wafer held in position on the chuck, chamber 548 is pressurized to raise the wafer into contact with the bottom of the mask. A bearing 584 comprising a section of a sphere is secured to stem 566 of chuck plate 560 and is received in the conical shaped upper portion 570A of bore 570. Clearance space between chuck plate 560 and end member 550 permits tilting of the chuck plate to assure face-to-face engagement of the wafer with the mask when the chuck is raised. The center of radius of spherical section bearing 584 is located at approximately the center A of the top surface of chuck plate 560 to prevent transverse movement of the chuck plate during pivotal movement thereof. This substantially eliminates scraping of the wafer across the mask when they are brought into face-to-face engagement. When chuck plate 560 is lowered, frictional engagement between bearing 584 and the walls of bearing receiving well 570A is sufficient to maintain the parallel relationship between the adjacent faces of the mask and wafer.

A locking device 586 comprising a locking ring 588 having an annular groove 590 in its inner wall surrounds vertically movable sleeve 552. Jaws 594 abut against a resilient, inflatable, annular tube 592 seated on the V-shaped bottom of groove 590. These jaws comprise sections of a ring having a triangular-shaped groove in its outer wall to seat inflatable tube 592. Tube 592 is connected through a flexible tube 596 and a valve to a source of compressed air. When the valve is opened, tube 592 is inflated and jaws 594 are urged radially inward into clamping engagement with sleeve 552 thereby locking ring 588 to sleeve 552. When tube 592 is deflated, jaws 594 and sleeve 552 are slidable relative to one another. However, even when resilient tube 592 is deflated, it provides sufficient frictional engagement between jaws 594 and sleeve 552 to prevent ring 588 from sliding downward under the force of gravity. Vertical movement of ring 588 is limited in the upward direction by an inwardly directed flange 598 of chuck holder section 498A and is limited in the downward direction by an adjustable stop ring 600 threadedly engaging the inner lower end of section 498A.

A ring gear 604 is attached to stop ring 600. A spur gear 606 is affixed to shaft 608 for rotating ring gear 604. Shaft 608 is coupled through bevel gears 610 and 612 to a shaft 614 extending from the front of the instrument (Figure 7). Thus, the amount ring 588 travels between flange 598 and stop ring 600 is adjusted by rotating shaft 614 to rotate stop ring 600.

The wafer is loaded onto vacuum chuck 312 by moving it onto perforated plate 564 when the chuck is in the lowered position. The chuck is then raised to bring the wafer into face-to-face engagement with the mask. Tube 592 is deflated during this operation so that upward movement of locking ring 588 with the chuck is stopped by flange 598 while the chuck continues moving upwardly to bring the wafer into engagement with the mask. With the chuck in the raised position and locking ring 588 abutting on flange 598, tube 592 is inflated to clamp the locking ring to sleeve 552. The chuck is then lowered slightly to an intermediate position spacing the wafer and mask apart for alignment. This is done by connecting a vacuum to chamber 548 to move sleeve 552 and chuck plate 560 downwardly. Downward movement of sleeve 552 is limited by engagement of locking ring 588 with stop ring 600. The downward movement of sleeve 552 is the same for wafers of all thicknesses since locking ring 588 is clamped to the sleeve only after the wafer and mask are brought into engagement. The wafer is therefore always spaced a predetermined distance below the mask during the aligning process. (This spacing is readily adjusted by rotating shaft 614, but once set is seldom readjusted). Thus, the microscope remains in focus for wafers of different thickness eliminating the need for refocus after each wafer alignment. The chuck is reloaded to the wafer loading and unloading position by deflating tube 592 to release locking ring 588 from sleeve 552 and permit the sleeve to drop to the lowermost position.

Referring now to Figure 12, a plate 622 is attached to the top of plate 500. A loading slide 652 is secured at one end to a rack 658 reciprocally mounted between two ways 660 attached to plate 500. One of these ways is segmented to permit slide 652 to be driven by a pinion gear 662 attached to the shaft of a reversible drive motor. The other end of slide 652 has a V-shaped head 666 adjustably positionable along the slide to engage wafers of different diameters. This head comprises two arms 668 extending at right angles to each other and opening generally in the direction of chuck 312 for engaging a flat portion of generally circular-shaped wafer 38A. This flat portion is provided along a line dependent upon the crystal structure of the wafer. When the drive motor is energized for rotation in one direction, slide 652

is drawn forward to move wafer 38A across plate 622 and to a position directly above chuck 312. Switches 678 and 680 are actuated at the ends of the stroke of slide 652 for connecting the vacuum source to chuck 312 to draw the wafer down into tight engagement with the chuck and for then reversing the direction of rotation of the drive motor to return the slide to the illustrated retracted position. In the retracted position, an arcuately recessed portion 664 of slide 652 permits the wafer on the chuck to be viewed from above with the microscope.

After the wafer has been precisely aligned with the mask and exposed to ultraviolet light from lamp 50 through the mask, wafer chuck 312 is returned to the loading and unloading position and the vacuum source is disconnected from the chuck. The wafer is then pushed off the chuck by an ejector slide 654 oriented at an acute angle with loading slide 652. Ejector slide 654 comprises a rack 690 reciprocally mounted between two ways 692 secured to plate 500 and driven by a pinion gear 694 attached to the shaft of a reversible drive motor. Rack 690 has a pusher head 696 with a V-shaped notch 698 in its forward end. A recess 700 in the bottom of head 696 along notch 698 is lined with a pad of flexible material. When the ejector slide drive motor is energized for rotation in one direction, pusher head 698 is driven forward beneath loading slide 652 to move the wafer from chuck 312 across plate 622 to a storage tray 628 that may be rotatably mounted beneath a wafer receiving recess 638 in plate 622. At the end of the forward stroke of pusher head 696, the ejector slide drive motor is energized for rotation in the opposite direction to return the ejector slide to the illustrated retracted position.

WHAT WE CLAIM IS:—

1. Alignment apparatus for aligning a mask with a workpiece having a light-sensitive film to be exposed through the mask, said alignment apparatus comprising a base unit having a first holder for the mask, a second holder for the workpiece, and control apparatus for moving at least one of the holders relative to the other to bring the mask and the workpiece into alignment, said alignment apparatus further comprising an optical unit mounted on the base unit and being characterized in that the optical unit includes an ocular lens system, a rotatable turret having a plurality of positions, at least one objective lens system mounted on the turret for alignment with the ocular lens system in at least one of the turret positions to provide a magnified view of the mask and the workpiece on the first and second holders and an illumination system including an optical element mounted on the turret for directing light on to the workpiece through the mask in another

of the turret positions to expose the light-sensitive film on the workpiece.

2. Alignment apparatus according to Claim 1, wherein said base unit has additional control apparatus for moving the first and second holders together as a unit and in that the ocular lens system of said optical unit remains stationary when the holders are moved together as a unit and then one hold is moved relative to the other for alignment of the mask and the workpiece, said turret being rotatable for bringing an objective lens system into alignment with the stationary ocular lens system when the holders are to be moved together as a unit and when one holder is to be moved relative to the other.

3. Alignment apparatus according to Claim 1 or 2, wherein said optical unit includes a plurality of objective lens systems each mounted on the turret for alignment with the ocular lens system in a different one of the turret positions to provide a magnified view of the mask and the workpiece on the first and second holders, said plurality of objective lens systems comprising a single field row and column objective lens system and at least a first split field objective lens system.

4. Alignment apparatus according to Claim 3, wherein said optical unit includes a second split field objective lens system mounted on the turret diagonally opposite the first split field objective lens system in position for alignment with the ocular lens system in still another turret position to provide a magnified view of the mask and the workpiece on the first and second holders, said optical unit further including adjustment apparatus having a pair of members extending from diagonally opposite sides of the turret adjacent to the first and second split field objective lens systems, each of said members being manually operable for adjusting the separation of the optical axes of a different one of the split field objective lens systems independently of the other.

5. Alignment apparatus according to Claim 3 or 4, wherein the illumination system of said optical unit includes a first source of light for exposing a light-sensitive film, the optical element mounted on the turret comprising a mirror and being positioned for directing light from the first light source onto the workpiece through the mask in said other of the turret positions to expose the light-sensitive film on the workpiece, said illumination system further including a filter retractably movable into the path of light from the first light source to provide filtered light for illuminating the mask and the workpiece, one of said objective lens systems including an optical element for vertically directing the filtered light from the first light source through that objective lens system onto the mask and the workpiece on the first and second holders when that objective lens system is



is drawn forward to move wafer 38A across plate 622 and to a position directly above chuck 312. Switches 678 and 680 are actuated at the ends of the stroke of slide 652 for connecting the vacuum source to chuck 312 to draw the wafer down into tight engagement with the chuck and for then reversing the direction of rotation of the drive motor to return the slide to the illustrated retracted position. In the retracted position, an arcuately recessed portion 664 of slide 652 permits the wafer on the chuck to be viewed from above with the microscope.

After the wafer has been precisely aligned with the mask and exposed to ultraviolet light from lamp 50 through the mask, wafer chuck 312 is returned to the loading and unloading position and the vacuum source is disconnected from the chuck. The wafer is then pushed off the chuck by an ejector slide 654 oriented at an acute angle with loading slide 652. Ejector slide 654 comprises a rack 690 reciprocally mounted between two ways 692 secured to plate 500 and driven by a pinion gear 694 attached to the shaft of a reversible drive motor. Rack 690 has a pusher head 696 with a V-shaped notch 698 in its forward end. A recess 700 in the bottom of head 696 along notch 698 is lined with a pad of flexible material. When the ejector slide drive motor is energized for rotation in one direction, pusher head 698 is driven forward beneath loading slide 652 to move the wafer from chuck 312 across plate 622 to a storage tray 628 that may be rotatably mounted beneath a wafer receiving recess 638 in plate 622. At the end of the forward stroke of pusher head 696, the ejector slide drive motor is energized for rotation in the opposite direction to return the ejector slide to the illustrated retracted position.

WHAT WE CLAIM IS:—

1. Alignment apparatus for aligning a mask with a workpiece having a light-sensitive film to be exposed through the mask, said alignment apparatus comprising a base unit having a first holder for the mask, a second holder for the workpiece, and control apparatus for moving at least one of the holders relative to the other to bring the mask and the workpiece into alignment, said alignment apparatus further comprising an optical unit mounted on the base unit and being characterized in that the optical unit includes an ocular lens system, a rotatable turret having a plurality of positions, at least one objective lens system mounted on the turret for alignment with the ocular lens system in at least one of the turret positions to provide a magnified view of the mask and the workpiece on the first and second holders and an illumination system including an optical element mounted on the turret for directing light on to the workpiece through the mask in another

of the turret positions to expose the light-sensitive film on the workpiece.

2. Alignment apparatus according to Claim 1, wherein said base unit has additional control apparatus for moving the first and second holders together as a unit and in that the ocular lens system of said optical unit remains stationary when the holders are moved together as a unit and then one hold is moved relative to the other for alignment of the mask and the workpiece, said turret being rotatable for bringing an objective lens system into alignment with the stationary ocular lens system when the holders are to be moved together as a unit and when one holder is to be moved relative to the other.

3. Alignment apparatus according to Claim 1 or 2, wherein said optical unit includes a plurality of objective lens systems each mounted on the turret for alignment with the ocular lens system in a different one of the turret positions to provide a magnified view of the mask and the workpiece on the first and second holders, said plurality of objective lens systems comprising a single field row and column objective lens system and at least a first split field objective lens system.

4. Alignment apparatus according to Claim 3, wherein said optical unit includes a second split field objective lens system mounted on the turret diagonally opposite the first split field objective lens system in position for alignment with the ocular lens system in still another turret position to provide a magnified view of the mask and the workpiece on the first and second holders, said optical unit further including adjustment apparatus having a pair of members extending from diagonally opposite sides of the turret adjacent to the first and second split field objective lens systems, each of said members being manually operable for adjusting the separation of the optical axes of a different one of the split field objective lens systems independently of the other.

5. Alignment apparatus according to Claim 3 or 4, wherein the illumination system of said optical unit includes a first source of light for exposing a light-sensitive film, the optical element mounted on the turret comprising a mirror and being positioned for directing light from the first light source onto the workpiece through the mask in said other of the turret positions to expose the light-sensitive film on the workpiece, said illumination system further including a filter retractably movable into the path of light from the first light source to provide filtered light for illuminating the mask and the workpiece, one of said objective lens systems including an optical element for vertically directing the filtered light from the first light source through that objective lens system onto the mask and the workpiece on the first and second holders when that objective lens system is

aligned with the ocular lens system, said illumination systems still further including a second source of light for illuminating the mask and the workpiece, another of said objective lens systems including an optical element for vertically directing light from the second light source through that objective lens system onto the mask and the workpiece on the first and second holders when that objective lens system is aligned with the ocular lens system.

6. Alignment apparatus according to Claim 1, wherein said base unit has additional control apparatus including a first manually operated lever adapted for operation by one hand of the operator to move the first and second holders together as a unit and in that said first-mentioned control apparatus includes a second manually operated lever adapted for operation by the other hand of the operator to move one of the holders relative to the other, said second manually operated lever having spaced first and second fulcrums that may be selectively employed to provide the second manually operated lever with first and second mechanical advantages for coarse and fine alignment adjustments.

7. Alignment apparatus according to Claim 6, wherein said first-mentioned control apparatus includes a first movable member coupled to a support for one of the holders, a second movable member coupled to a support for the other of the holders, first and second pivot connections attached to the second manually operated lever at spaced positions therealong, pivot apparatus coupling the second manually operated lever at another position therealong to the first movable member, and releasable locking apparatus for selectively coupling either the first or the second pivot connection to the second movable member to provide the first or the second fulcrum.

8. Alignment apparatus according to Claim 7, wherein said control apparatus includes apparatus for releasably locking the second movable member to the base unit during operation of the second manually operated lever so as to lock said other holder against movement during movement of said one holder relative thereto.

9. Alignment apparatus according to any of the preceding claims, wherein said second holder is movable between a retracted position for loading and unloading the workpiece therefrom and an extended position for bringing a surface of the workpiece into face-to-face engagement with a surface of the mask on the first holder and being still further characterized in that stop apparatus is operable when the second holder is retracted from the extended position to stop the second holder at a position intermediate the retracted and extended positions so that workpieces of different thicknesses are each spaced

the same predetermined distance from the mask.

10. Alignment apparatus according to Claim 9, wherein said stop apparatus includes first and second stop members and a releasable locking device locked to the second holder in the extended position, said locking device abutting upon the first stop member in the extended position and upon the second stop member in the intermediate position and being released to permit return of the second holder to the retracted position.

11. Alignment apparatus according to Claim 9 or 10, wherein said optical unit is mounted on the base unit for pivotal movement between a lowered operative position and a raised inoperative position making the first holder accessible for loading and unloading the mask and in that said base unit has a loading and unloading platform with an aperture for receiving the second holder, said second holder being substantially even with the top of said platform in the retracted position and being raised through said aperture for bringing the workpiece into engagement with the mask on the first holder in the extended position, said base unit further having loading apparatus movable along said platform for moving the workpiece onto the second holder at said aperture when the second holder is in the retracted position and for moving the workpiece off the second holder when the second holder is in the retracted position.

12. Alignment apparatus as claimed in Claim 1 or 2, wherein said optical unit includes a plurality of objective lens systems each mounted on the turret for alignment with the ocular lens system in a different one of the turret positions to provide a magnified view of the mask and the workpiece on the first and second holders, said plurality of objective lens systems comprising at least a pair of split field objective lens systems, and in that said optical unit includes apparatus for adjusting the separation of the optical axes of each of said split field objective lens systems.

13. Alignment apparatus as claimed in Claim 1 or 2, wherein said illumination system includes apparatus for providing illuminating light to illuminate the workpiece and for providing exposure light to expose the light-sensitive film on the workpiece, said objective lens system includes apparatus for directing the illuminating light onto the workpiece to illuminate the workpiece when the objective lens system is aligned with the ocular lens system, said optical element being mounted on the turret for directing the exposure light onto the workpiece to expose the light-sensitive film thereon when the turret is rotated to said other of the turret positions, and said illumination system further includes apparatus movable into the path of the expo-



sure light for preventing the exposure light from reaching the workpiece and movable out of the path of the exposure light for permitting the exposure light to reach the workpiece when the turret is rotated to said other of the turret positions.

14. Alignment apparatus according to Claim 1, wherein said control apparatus includes a first manually operated lever adapted for operation by one hand of the operator to move one of the holders relative to the other, said base unit includes releasable locking apparatus for locking said other of the holders against movement during movement of said one of the holders relative to said other of the holders, said base unit has additional control apparatus including a second manually operated lever adapted for operation by the other hand of the operator to move the first and second holders together as a unit, and said base unit further includes apparatus for releasing said releasable locking apparatus during operation of said second manually operated lever.

15. Alignment apparatus according to Claim 1, wherein said control apparatus includes a manually operated lever for moving one of the holders relative to the other, said manually operated lever having spaced first and second fulcrums that may be selectively employed to provide the manually operated lever with first and second mechanical advantages for coarse and fine alignment adjustments.

16. Alignment apparatus according to any of Claims 1 to 10 or 12 to 15, wherein said base unit includes apparatus for loading workpieces onto the second holder.

17. Alignment apparatus according to Claim 16, wherein apparatus for loading workpieces onto the second holder comprises reciprocally movable apparatus for loading workpieces onto the second holder and unloading workpieces from the second holder when the second holder is in the retracted position.

18. Alignment apparatus according to Claim 1, wherein said base unit has additional control apparatus for moving the first and second holders together as a unit and in that said ocular lens system remains stationary when the holders are moved together as a unit and when one holder is moved relative to the other during alignment of the mask and the workpiece.

19. Alignment apparatus according to Claim 18, wherein said first-mentioned control apparatus includes a first manually operated lever adapted for operation by one hand of the operator to move one of the holders relative to the other, said base unit includes releasable locking apparatus for locking said other of the holders against movement during movement of said one of the holders relative to said other of the holders, said additional control apparatus includes a second manually operated lever adapted for operation by the other hand of the operator to move the first and second holders together as a unit, and said base unit further includes apparatus for releasing said releasable locking apparatus during operation of said second manually operated lever.

20. Alignment apparatus according to Claim 18, wherein said first-mentioned control apparatus includes a manually operated lever for moving one of the holders relative to the other, said manually operated lever having spaced first and second fulcrums that may be selectively employed to provide the manually operated lever with first and second mechanical advantages for coarse and fine alignment adjustments.

21. Alignment apparatus substantially as described herein with reference to the accompanying drawings.

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