A PIONEERING STEP AND REPEAT CAMERA

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ABSTRACT

Before commercial cameras were available, a twelve barrel step and repeat camera was constructed using one light source. Magnification adjustment, plate flatness, azimuthal control, pulsed exposure, grid register, random interconnection and also maintenance methods devised are summarised. A matched reduction camera completed the system.

1.0 Introduction

This paper recounts the development of a step and repeat camera for a microphoto mask system at Teledyne Semiconductor in Mountain View, California. This camera, designed and built in-house, was modified progressively over several years; in its final configuration as described at the end of this paper only the objective lenses and three other pieces of the original camera were left.

The camera was first built and placed in operation in 1961, when step and repeat cameras with suitable characteristics were not yet commercially available. For nearly ten years thereafter, this was the only step and repeat camera at Teledyne Semiconductor. It was initially designed so as to be easily adjusted and modified, since it was thought that after experimental determination of parameters on this equipment a following model of camera would be made with all adjustments optimized and fixed. However, a second-generation camera of this type was never built. Once the prototype was operative, demand for its output was so continuous and insistent, that always thereafter modifications had to be carefully pre-planned to minimize down-time. During the first few years' use of this camera, Teledyne Semiconductor was wholly dependent upon its output. Products totalling many millions of dollars originated in this apparatus.

A step and repeat camera is critical to the manufacture of transistors and microcircuits; the quality of the product is dependent upon the quality of the stepped and repeated masks. Thus the masks determine the yield rate of useful devices. Without masks, nothing can be made by the planar process.

In the development of the maskmaking system we found it desirable to use an abbreviated language, shown in Table 1.1, to describe various elements and steps in the operation. The basic steps in the system are widely used in the industry. It is common practice for the designer of a new semiconductor device to produce a drawing or a set of drawings wherein the geometry of the required masks is drawn on grid paper to a suitable scale. It has been our practice to make blueline prints from these drawings, and by hand to assign coordinates to the line elements of the design, and to mark the digitized coordinates on the blueline print, which is then known as a P_0. This digitized drawing was used by the coordinatograph operator to produce a precision artwork master pattern on glass plate, by cut-and-peel techniques. The usual scale of the artwork master, or P_1, was 200x final size. At the next stage the P_1 was photographically reduced on a large precision reduction type camera (Ref. 1) to make a glass plate commonly called the first reduction or "reticle," a P_2 glass plate, at 20 x final size. These first reductions were placed in the step and repeat camera and reduced further as the camera stepped to produce the master mask or step photo

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plate, P_3. Sets of P_3s, or P_4 and P_5 copies made from them by contact printing, are then used as photoengraving stencils to define the areas to be worked on a silicon wafer, at each state in the process of making an array of semiconductor devices on the wafer.

Table 1.1
Mask System Terminology

Item	Name	Character
Designers Drawing	--	Grid Paper
Encoded	P_o	Digitized Coordinates
Master Pattern ("Ruby")	P_1	Precision Artwork Cut and Peeled (unreduced scale)
First Reduction ("Reticle")	P_2	Glass Plate
Master Mask	P_3	Step and Repeated glass Plate
Working Mask	P_4 P_5	Contact Prints from P_3

1.1 Design Goals

In 1961 when this system was being set up, contact printed working masks were usually of poor quality, and therefore the P_3s themselves were used as working masks. This practice led us to choose a step and repeat camera design with a great many lens barrels so that a great many P_3s could be made at once; a camera with 12 barrels, or channels, was decided upon.

Initially, the overall performance goal of the camera was that the stepped and repeated P_3s made on it should be capable of printing 2.5 micrometers (0.1 mil) lines, in register, when successive prints were made with different P_3s. This goal subsumes all effects of lens resolution and optical distortion, magnification and focus errors, crooked camera ways, and all other error sources; but it allows trade offs.

2.0 Optics

From the outset, it was realized that this step and repeat camera would be a developmental apparatus. Not only would it produce microphotomasks for development of transistors and microcircuits, but the processes and the camera would themselves be subject to continuous change. In essence the design became a vertical optical bench, with a horizontal carriage for the final photoplates movable in the plane of the image in X and Y coordinates. Prior experience with optical reduction stepping printers for motion picture use led to immediate investigation of the probable sources of defects in images. Table 2.1 summarizes the common contaminant particle sizes likely to degrade or make unusable the images involved. These contaminants were found to fall into the categories of glass chips such as from the edges of the glass plates used; hair and skin flakes; and dust particles either settled, which are commonly large, or airborne, which are on an average 5 microns. No conditions were observed which would cause upward projection of these particles, and it was therefore decided that it was good design to have the smallest image face down. An opaque particle that falls upon the smallest image will be contact printed at 1x, causing the maximum amount of damage; the same particle on the P_2 image will be projection printed at 20x reduction and will do minimum damage. Throughout the use of this equipment, we never found any evidence to contradict this basic design assumption, but we were always careful to avoid setting up convective or turbulent air currents in the camera room.

Table 2.1
Common Particle Contaminants

Type	Size	1/20 Size
Glass Chips	20 mils	1 mil
Hair	4 mils	.2 mil (5 microns)
Dust		
Settling	4 mils (100 micron)	.2 mil (5 micron)
Average	.2 mil (5 micron)	.01 mil (0.25 micron)
Floating	.02 mil (0.5 micron)	.001 mil (0.025 micron)

It was observed that choosing the reduction ratio became a trade-off problem as a means of matching the modulation transfer requirements, imaging of foreign particle contamination, and making of the P_2 plates. A survey of the commercially available objective lenses and plates suitable for the 200 line pairs per millimeter spatial frequency goal led us to selection of a 20x reduction ratio from the P_2 to the P_3, with the plate characteristics shown in Table 2.2

Table 2.2
Plates

Plate	Size: Initial System	Size: Final System	Scale	Photographic Material
P_2	on 1x3" glass: one per channel 1.0" image MAX.	on 18x8" plate 12 channels per plate plus 2 fiducials 2.4" image MAX.	20 X	Kodak High Resolution Plate or Kodalith Ortho
P_3	on 1x3" glass .625 Dia. Field "50 Mil Device	on 2x2" glass 1.25" Dia. Field 105 Mil Device"	1 X	Kodak High Resolution Plate (earlier: Type 649GH "suitable for micro-electronics")

As 20x reduction is close to infinity correction of the geometric optics of such objectives, we found that a selected and closely matched group of double gauss objectives as described in Table 2.3 was available for the 12 lenses required for the 12 barrel camera. We bought them. The General Scientific Company tests of their SOLMAR double gauss microfilm type lenses indicate the limit of resolution feasible. In optical bench tests, and in subsequent use of these objectives in the camera, we achieved our goal of being able to make .10 mil lines (2.5 microns). (Note that this is not identical with white lines in dark backgrounds.)

Table 2.3
Objectives

Type:	Solmar "N" Double Gauss (D528L2)
Mfg.:	General Scientific Co. Chicago, Ill.
E.F.L.:	20 MM$\pm$ 2%
Aperture:	Design f/2 Stop f/4
Resolution*	359 lines/MM on Axis 320 lines/MM2MM off Axis
Plate to Plate:	9.527 in.@20x

*per supplier

Because the 12 lenses were not of identical focal lengths, although within the manufacturer's tolerance of $\pm$2%, it was not possible to design the camera with all P_2 images in one plane and all P_3 images in another; the magnification differences between channels would have been unacceptable. A single flat surface with openings and mechanical clamping of the glass plates for P_3 holding was tested. This requires 12 separate plates for P_2 images. Individual holders for P_2 plates for each channel requires each such P_2 to be aligned separately and very precisely. The second construction for matching magnifications places all P_2 images in one plane and varies the distance to each P_3 for magnification control. This was found to have advantages beyond the uniformity of magnification; accordingly, the camera was designed to have a single P_2 plate, with 12 adjustable lens mounts and 12 adjustable P_3 holders. The mounting of the objectives, focus, and magnification control posed basic design decisions. The choice appeared to be between complete precision design and a simple adjustable construction allowing great variability. As we had then no knowledge of the variations eventually to be required in the equipment, initial experiments used the barrel lens mount adapted to fit a fine-focus Bausch and Lomb microscope barrel assembly (part No. 31-29-0301). The microscope tube caused vignetting, and so when subsequent developments required elimination of vignetting for a better field of view, the tube was removed and a lens support bracket was fitted to the focusing mechanism. The fine focus microscope assembly proved quite desirable because of its straight-line translation, without dependence on screw threads or sliding sleeve fits for linear translation in focus of the objective; however, it did not provide for initial adjustment of the optical axis of the objective perpendicular to the photo plate. For this we designed a ball mount shown in Fig.2.1 which rotates the objective around the nodal point without changing other parameters. This simple two-piece axis rotation construction slides on the spherical ball surface for coarse settings, and apparently sets finally by minor flexure. It should be noted that because the Bausch and Lomb fine focus assemblies were used inverted from their designed position, spring pressure gravity compensators were required. Friction clamps were found necessary on both coarse and fine motions.

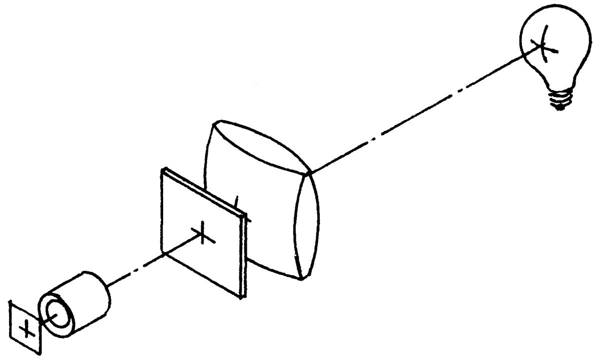


Figure 2.2
Basic Optics

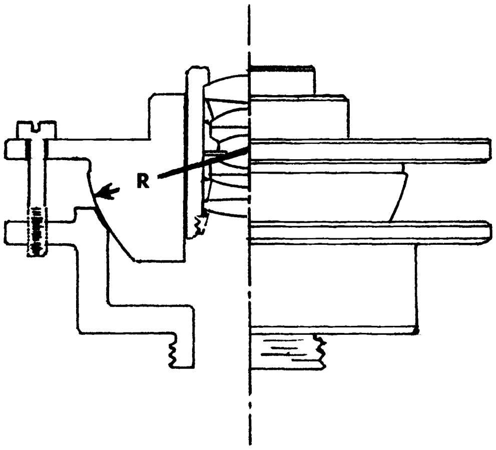


Figure 2.1
Ball Mount

The basic optics for one of the 12 barrels or channels of the camera are shown in Fig. 2.2 and consist of a single light source common to all channels, a condensing lens, the first reduction photo plate P_2, the objective, and finally the image P_3. We folded the systems between the lamp and the condenser, as shown in Fig. 2.3. The fold mirrors are plate glass but viewed as a group they approximate an off-axis parabola.

We found that an unfolded, straight-line system terminating with the image directly above the lamp was undesirable for several reasons: the heat of the lamp produces Schlieren degradation of the resolution and registration, and causes dimensional changes in the camera itself; also it probably would convect airborne particles upward through the system.

Initially the camera was set up to make masks on 1x3 inch microscope-slide sized photoplate (Fig. 2.4). This was the size commonly used by the the semiconductor industry at that

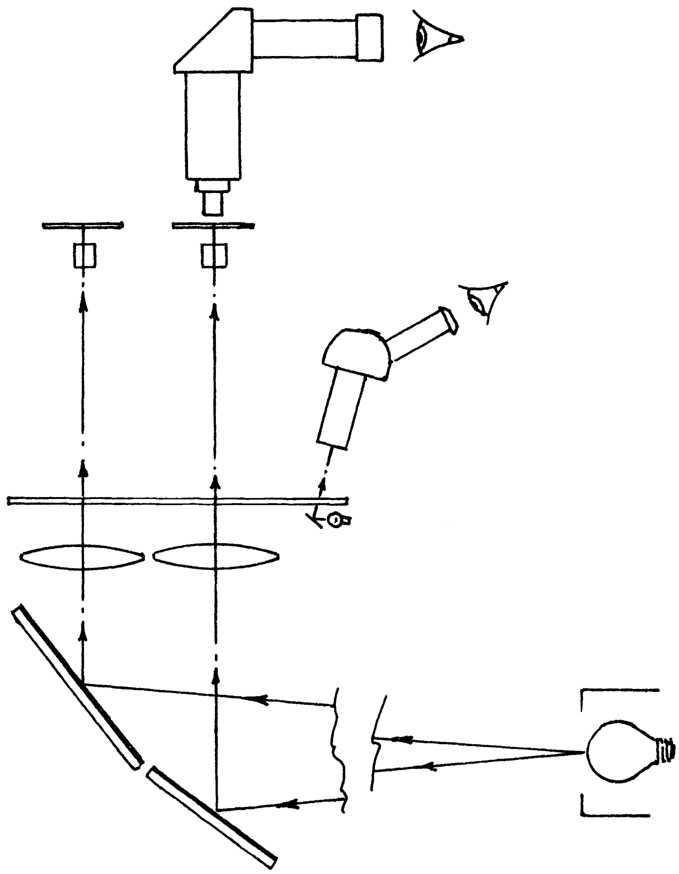


Figure 2.3
Folded Construction,
Single Lamp

time, when a silicon wafer three-quarters of an inch in diameter was considered enormous. But we found that during processing of the photoplate the influence of the edge of the plate can produce such dimensional shifts that precise registration became uncertain at the edge of a .625 inch diameter array. Accordingly, the camera was changed to make P_3s on 2x2 inch photoplate.

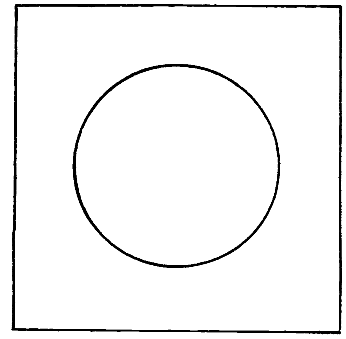


Figure 2.5
2x2 Inch Mask

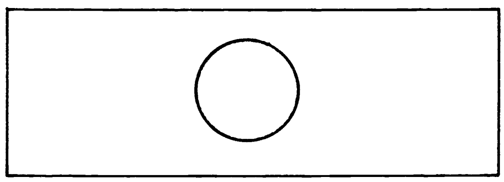


Figure 2.4
25x75mm (1x3 in.) Mask
(Microscope Slide)

Figure 2.5 illustrates the improvement in useful array area, gained with little increase in the cost of the high resolution photographic emulsion. To use this size of plate, the optical axis separation on the camera was chosen as 3 inches between adjacent lens barrels. We believe we were the first in the semi-conductor industry to use 2x2 plates. At the time, we thought we were being absurdly visionary in choosing a plate that could accommodate 1.5 inch diameter arrays.

3.0 First Reduction Plates

When all P_2 images are placed upon one photoplate of glass as shown in Figure 3.1, it becomes practical to place on this plate a single pair of fiducial alignment marks. These marks, shown as crosses on Figure 3.1, are spaced roughly 12 inches apart. This allows aligning all 12 P_2 patterns simultaneously, a great labor saving. Obviously the 12 inch distance between fiducial marks is an optical lever 4 to 6 times more effective than any to be had on a 2 to 3 inch P_2 plate. With this leverage, two 20x macroscopes equipped with reticle eyepieces allow manual orientation and placing of the P_2 plate in the camera holder. No auxiliary alignment equipment is required under these conditions. Implicit in this system of a 12-channel P_2, is the necessity of placing all patterns in proper rotational alignment on the P_2 photoplate at the time of exposure (Ref. 1).

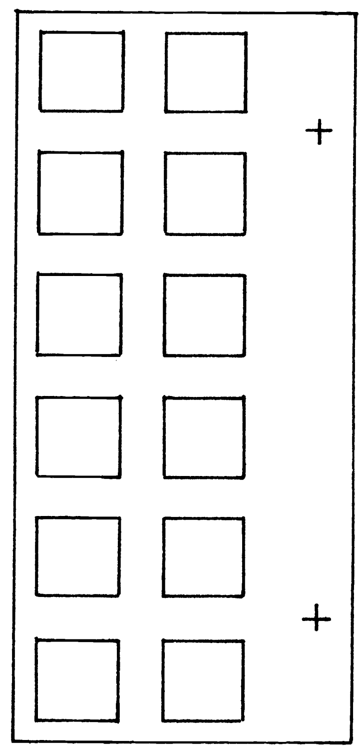


Figure 3.1
First Reduction Plate
(12 Channel)

Upon use of the unitary 12-channel construction, it was found that the fixed location of each channel on the P_2 led to the capability of selecting which type of artwork would go into which channel, thereby allowing assignment of the most critical artwork to the best-performing channel. It should be noted that in the early development of this camera, when only four channels had been built, the initial use of the unitary P_2 was with 8x10 inch glass photoplates, and the size was subsequently expanded for the 12 channel system.

In a later shakedown of tolerances of operation of the camera, the holder for the P_2 plate was upgraded from a simple friction slot holder. Vacuum pockets were milled into the reference surface of the holder frame, working on the emulsion surface (up) of the P_2 as the positioning clamp after P_2 alignment. When the camera needed correcting, the holder frame could be adjusted by 3 micrometer screw constructions to provide coarse positioning prior to final positioning of the P_3 system.

4.0 <u>Mask Plates</u>

The photographic glass upon which the emulsion is coated, for use in this type of apparatus, is commonly a select grade of glass. For the P_2 plates our experience was that deviation from flatness fell roughly around 1 mil per inch, and the 2x2 inch high resolution photographic plates were better than the P_2 glass, sometimes 0.5 mil per inch departure from flatness. (2x2 inch plates used on this camera were .060 inches thick.) Thus the departure from flatness on the P_2 between the vacuum rails 7 inches apart, could as a limit be 7 mils. The vacuum rail serves as a go-no go gauge for flatness along the 18 inch dimension and will not retain vacuum holding if the photo plate does not come flat against the rail, thus rejecting automatically any plate departing excessively in flatness along the longer dimension. As the relative aperture on the P_2 side of the objectives makes the system tolerant of small errors in depth of focus, out-of-flatness is not critical to image quality, the effect being confined to magnification error.

It can be shown theoretically that the out-of-flat P_2 is capable of making a 2/10th mil P_3 error which is quite significant, when it is realized that registration of lines of 1/10th mil is sought. As the worst problem occurs midway between the two rails, as for example in the image gap between channels 3 and 9, one would expect that a theoretical improvement would be gained from placing an additional vacuum rail along that area, but the possibility of random deformation shapes, such as a saddle, makes the advantage from an additional center rail diminish. In addition it must be noted that, on axis, no such positional deformation occurs and thus the smaller devices do not suffer from positional deformation as a function of glass flatness. Fortunately, during the useful years of this camera the tight registration devices were all small, and on axis normally.

Flatness of P_3 glass has similar problems. A vacuum clamp ring in the plate holder was constructed as shown in Figure 4.1. A vacuum channel was cut in a ring which was lapped and potted in place in the carriage which could be leveled and moved up and down by micrometer thimbles for magnification correction. As with the P_2, loss of P_3 vacuum indicates unacceptably out-of-flat plates, and the vacuum will pull in plates which depart only slightly from flatness. With the 1.25 inch diameter opening in the P_3 holder last installed in the camera, departures from the ideal focus plane were minimized to the wafer size in use at that time.

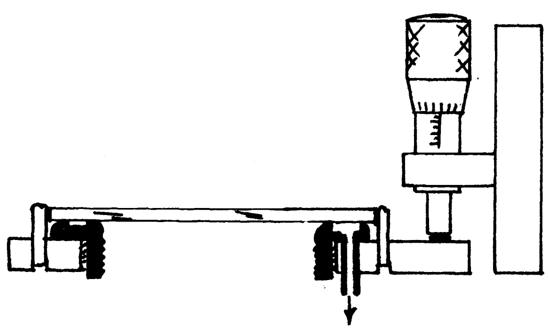


Figure 4.1
<u>P_3 Holder</u>
(Three point levelled lapped vacuum ring hold down)

The effect of out of flatness in the P_3 plane is a change of magnification of the entire pattern, not of only one side as in the case of P_2

errors. Thus if a P_3 plate bulges upward it then produces a larger image over the entire device, but as the exposures step to the edge of the plate they come nearer to the ideal plane and nearer to the normal size. For a semiconductor device of 2x2 milimeter die size (80x80 mils) a magnification change amounting to 1.25 microns (.05 mils) can result; however, when this is closer to the objective than the ideal focus, the thickness of the photographic emulsion of about 6 micrometers has a tendency to reduce the shrink slightly.

In order to minimize the effects of glass flatness when adjusting magnification and registration of the step and repeat camera, it is desirable to use a P_2 plate made of plate glass or a selected piece flatter than the normal glass, and similarly on the P_3.

5.0 Registration

The registration goal of this step and repeat camera was chosen as being suitable for production of geometry with 2.5 micrometer lines. It was assumed that ½ (1.25 micrometers) was a limit that could be achieved. Thus the total stack deviation considered allowable as a registration contribution is 1.25 micrometers. The effects of glass flatness have been treated above. In the selected lenses no effects of variation in distortion of geometrical optical character were detected. With the ball mount lens corrections for mechanical mount alignment, tilted axes were corrected to the point where keystone errors were not measurable in this system. The remaining sources of registration error to be discussed are the ways and the stepping system.

The original set of ways purchased for the developmental studies were hand scraped. The equipment was built and used in a clean room; initially this was approximately NASA class 500, and finally NASA equivalent of class 50. Apparently, the cleaner the room, the fewer the particles deposited in the lubricants to form a slurry, and the sooner the upsets of the hand scraping alignment ceased to lubricate, galled, and went out of straightness. Efforts to locate improved lubricants were futile, as the lubricants either spread over the optics, or failed to lubricate. A second set of ways, of relatively superior quality, was purchased, but it was found they exhibited two peaks. By autocollimation these were found to be upsets produced by the manufacturer, who had drilled the mount positions through the ways subsequent to precision grinding of the bearing surfaces.

The departure from theoretical conditions of straight ways and its influence on registration will be aided by Figure 5.1. This schematic uses a line as the X ways and another at a right angle to that as the Y ways. The Y ways are hitched to a schematic tray bearing the 12 P_3s. The distance y from the X ways is shown to the center of the tray. The horizontal rotational angle from the centers theta induces delta X as shown. The radius length on theta to channel 7 is roughly 370 millimeters, at the end of which registration is sought to 1 micrometer roughly. This corresponds to 0.6 seconds of arc.

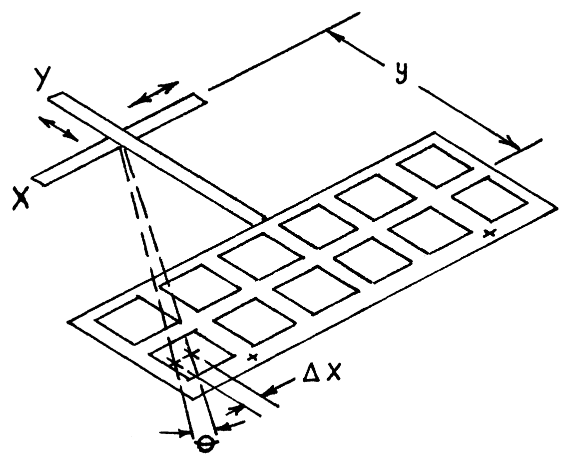


Figure 5.1
Registration Effect of Ways Deviation

In order to get the straightest ways possible we hand-corrected them while guiding our work with an autocollimator; when we had gone as far as we could we then selected the straightest two inches of travel on each way and made that the operating range of travel.

An unexpected characteristic of this camera design is its insensitivity to the effects of lead-screw and positioning errors. A positioning error in X or Y has <u>no</u> effect on the accuracy of registration of the masks.

The masks must match each other because they were all borne on the same supporting carriage; they have all been shifted the same distance, in the same direction, before each successive exposure. Even if the distance were wrong, it was the same on every mask, and they will register. But it cannot be expected that they will register to a mask from another set of 12 that were made on another camera run, without reproducible stepping intervals.

7.0 Discussion

At the camera's last inventory late in 1971, it was found that of the original camera as designed, besides the objective lenses, only one frame and two other original parts remained in the final camera. The frame is that supporting the mirror segments and the parts are the granite base and column with the toolmakers angle plate mounted thereupon. Mounted on the P_3 plate carriage assembly will be seen on top of camera a stage carrying a plate upon which there is a glass bearing a diamond ruled grid (Fig. 7.1). This is illuminated by a microscope using a lamp at the eyepiece "exit" pupil. This lighting matches the viewing microscope twin, which projects the grid upon a rear-projection screen for microscope viewing (commercial item). On the round viewing screen a number of geometries have been used experimentally. A simple cross line is satisfactory providing its exact center is missing. By motion of the X and Y cranks, the image on the microscope screen will be shifted from one intersection to the next for the exposure when the carriage is at rest, and the torque on the drive screws relaxed. By use of positional location by reference to a ruled grid such variables as the grease on the screw threads, the differences between operators, and wear, are no longer of influence; and positions are repeatable within reasonable limits of vision.

The metal carriers for the ruled grids have a long separation between the reference locating buttons, thereby making replacement in registor far more accurate. In this construction a steel surface was lapped and brought to register against pins by magnetic attraction.

With readily interchangeable grids it is practical to make new step and repeat patterns to match previously made mask sets, or to use as a grid

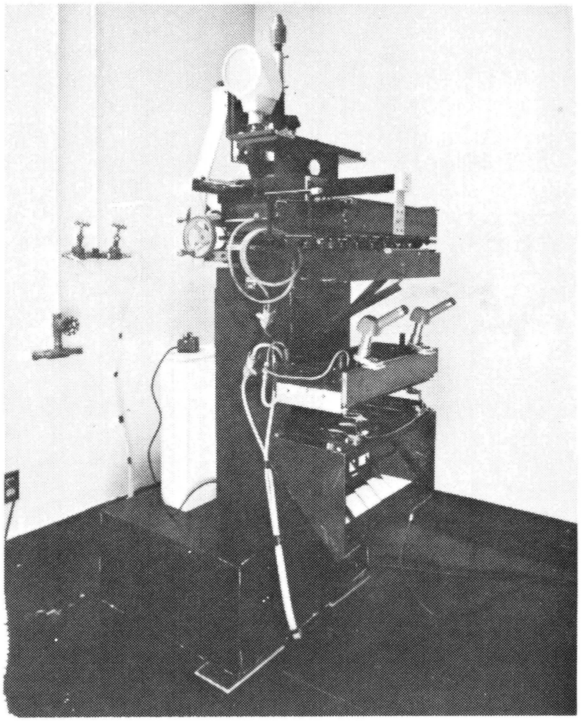


Figure 7.1
Final Camera
(Protective housing removed, electronics cabinet not shown)

another mask from another camera which is to be matched, including its errors. This process allows duplicating step and repeat runs made on less precise constructions, including those masks made on the same camera prior to this modification, during the time when only screwthread positioning was used. It should be noted that when screwthread positioning was used, registration between the 12 masks of a given run was the same as with registration between any set of masks on a given run on the camera, the difference being that registration between successive runs was radically improved using the ruled grid comparator.

When this system of parasitic registration on the stepping intervals of another mask became useful, the ability to duplicate "from the dead run" gave these the name of "spook" masks. Perhaps the most enjoyable feature of this method of step and repeat dicing-interval location is the total absence of any need for numerical setting or calculation. It must be remembered however, that axial alignment is required.

7.2 Interconnection Patterns

By the use of reflection illumination from a probed wafer mounted on the position of the ruled grid, and axially aligned, it becomes practical to generate interconnection or disconnection mask patterns for that wafer by the same method. For alignment of wafers and "masks to be spooked" the ruling apparatus was used for a reference grid.

7.3 Automation

By selection of photocell sensitivity and the color of the pattern placed over the microscope viewing screen, integration of the light passing through the trigger slit to the photocell was used to activate pulse illumination in place of the enlarging lamp normally used for exposure. For these tests the camera was equipped with a bead chain motor drive on the X and Y axis also. These were controlled manually in the feasibility tests. As pulsed exposure occurred at each intersection of the ruled grid, no counting logic was required. However, it must be mentioned that it is necessary to make a different ruled grid for each step and repeat raster. During the tests the operator spent most of his labor returning the camera to the next line, as the automated axis did not position satisfactorily for a stop. In the previously discussed information on registration, it will be seen that the requirements are quite demanding. While feasibility in principle was clearly demonstrated in automation, the vibration and flexure destroyed the quality of the mask, and the automation system was removed.

7.4 Housing

The room in which the camera was placed was provided in its final form with a very excellent air handling system which maintained excellent temperature control and contaminating particle control; however, this did not eliminate other hazards. One workman put his foot through the ceiling from above and nearly destroyed the camera. On another occasion, an accident in the epitaxial reactor area flooded the room with corrosive materials. Consequently, a housing was built for the camera which totally enclosed it and which was closed whenever the camera was not in use. It was also found that this housing had a tendency to integrate the variations in temperature control which occurred during power outages, thus increasing the productive time availability of the apparatus.

7.5 Operation and Service

Table 7.5 relates performance in the various configurations of the camera as it developed. Table 7.5 lists operational characteristics, not experimental and development performance. The radical change in maintenance down-time is due to clamping the focus mechanisms on the fine focus bodies for the objective lenses, straightening the ways, developing better lubrication, and the use of the grid step and repeat registration system, removing dependence on the screwthread location. As the optical grid also indicated deviation from straightness of the ways in both X and Y, this continuous exposure by exposure monitoring of the mechanical operation of the camera was of considerable value in improving quality, and alerting the crew to maintenance requirements. It also revealed continuous difficulty in maintaining matched orthogonality between the ways of the screwthread comparator which ruled the grids, and the translation ways of the step and repeat camera. With this information, operators ruling the grids and operating the camera developed improved manipulative capability, thus minimizing the errors.

Conclusions

8.1 Optical Limits

In the equipment described, it was not anticipated at the outset that devices of the size finally sought would be required, and the optical centerline to optical centerline spacing of 3.0 inches limited the size of the die size on the P_3. The objective lens was capable of larger size, but reconstruction of the equipment at the near end of useful production time was not merited.

The use of a single lamp for exposure of all channels introduces uniformity of exposure, both a blessing and a curse. The problem arises from the difficulty with lines near the limits of the system which on occasion require more exposure. It was originally planned that neutral density filters, out of focus below the P_2 and over the condenser tray, would be used to correct for this, if unsharp masking were not used.

Table 7.5
Configuration Performance

	Initial	Pre Grid	Final
Number of Channels	4	12	12
Die Size	50 mil	80 mil	105 mil
Mask Size	1x3"	2x2"	2x2"
Exposure Control	Shutter, & timer	on-off lamp, Volt. Reg. & Timer	Watt-sec integration, on-off lamp
Size difference between channels	.5 mil	.08 mil	.05 mils
Azimuthal Register	.5 mil	.08 mil	.08
Re-run Register	2.5 mil	.8 mil	.08
Reduction	20x	20x	20x
Maintenance Downtime	50%	5%	.25%
Rejects	50%	10%	5%

8.2 X-Y Ways

In construction of this step and repeat camera, commercially available ways of a simple variety were used with the P_3 tray hanging on one end of them. Counter-weighting to avoid unequal load was used, but every registration test indicated that it is superior in basic mechanical engineering to place the P_3 position in the center of the ways. The trend in semiconductor mask making is to increase the die size, while the pressure for smaller line limits forces doubly tighter characteristics on the apparatus. From our experience with this step and repeat camera it is not recommended that the cantilever construction we used be employed for other than development purposes.

8.3 Reduction Ratios

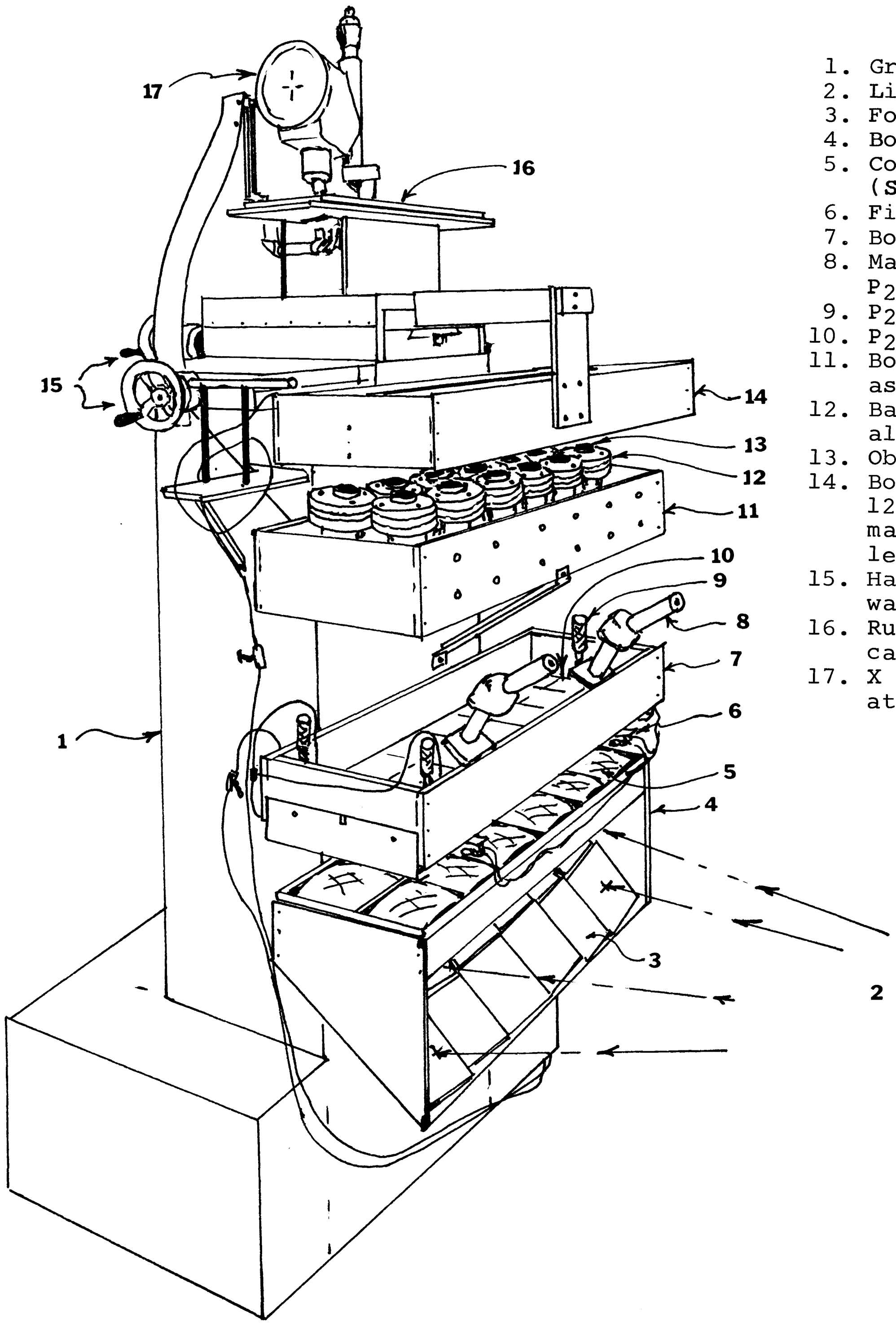
This camera was designed and in operation before there was any known discussion of the now-common 10 times reduction ratio in step and repeat cameras. Use of 20 times reduction has proved satisfactory and very convenient, making for easier spotting of emulsion defects, alignment and related operations. In view of this, we recommend serious consideration of reduction ratios between 20 and 200 times in the stepped reduction of the camera.

8.4 Fixed versus Adjustable Design

Of the basic mechanical components, only the X-Y ways were commercial products, the rest being manufactured in our machine shop without high precision requirements. As the camera room was temperature stabilized, the use of aluminum for major structural elements was tolerated as an expedience. This was a satisfactory compromise on materials for the performances sought in the original apparatus, but no longer acceptable by present step and repeat camera requirements. Hysteresis effects of temperature variations, changes in the character of photomaterials, and maintenance requirements convince one that the necessity for adjustive construction is essential for the optical photograph train of a step and repeat camera. The micrometer thimbles for leveling the P_3 holders were settable only with great difficulty to the required tolerances. The fine-focus microscope bodies gave less trouble. Autocollimation and laser alignment techniques did not prove of great value in the most important qualities of registration.

8.5 Dedication

This pioneering step and repeat camera has completed its useful service. Accordingly, in 1971 it was donated to the Foothill Electronics Museum located in the Space Science Center at Foothill College, 12345 El Monte Road, Los Altos Hills, California, 94022, on the San Francisco peninsula. As the basic operation of the camera does not require auxiliary apparatus, it should remain operable for demonstration for a number of



1. Granite column
2. Light source
3. Fold mirrors
4. Box
5. Condensing lenses (Squared, in frame)
6. Fiducial mark lamp
7. Box - P_2
8. Macroscope alignment P_2 fiducial marks
9. P_2 levelling jack
10. P_2 plate
11. Box, objective lens assemblies
12. Ball mount lens aligners
13. Objective lens
14. Box, P_3 12 separate carriers magnification and level adjustments
15. Hand cranks X and Y ways
16. Ruled grid plate and carrier
17. X and Y grid comparator

Figure 8
Step and Repeat Camera
Final Configuration (Museum)

years. The museum also has a quantity of masks made on the camera. (Fig. 8)

9.0 Acknowledgements

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References

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