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## ABSTRACT ABSTRACT

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

## 1.0 Introduction 1.0 Introduction

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

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

A step and repeat camera is cri-A step and repeat camera is critical to the manufacture of transis-tical to the manufacture of transistors and microcircuits; the quality tors and microcircuits; the quality

of the product is dependent upon the of the product is dependent upon the quality of the stepped and repeated quality of the stepped and repeated masks. Thus the masks determine the masks. Thus the masks determine the yield rate of useful devices. With-yield rate of useful devices. Without masks, nothing can be made by the out masks, nothing can be made by the planar process. planar process.

In the development of the mask - In the development of the maskmaking system we found it desirable making system we found it desirable to use an abbreviated language, shown to use an abbreviated language, shown in Table 1.1, to describe various in Table 1.1, to describe various elements and steps in the operation. elements and steps in the operation. The basic steps in the system are The basic steps in the system are widely used in the industry. It is widely used in the industry. It is common practice for the designer of a common practice for the designer of <sup>a</sup> new semiconductor device to produce a new semiconductor device to produce <sup>a</sup> drawing or a set of drawings wherein drawing or a set of drawings wherein the geometry of the required masks is drawn on grid paper to a suitable drawn on grid paper to a suitable scale. It has been our practice to scale. It has been our practice to make blueline prints from these draw-make blueline prints from these drawings, and by hand to assign coordin-ings, and by hand to assign coordinates to the line elements of the design, and to mark the digitized coordinates on the blueline print, which dinates on the blueline print, which is then known as a  $P_O$ . This digitized drawing was used by the coordinato-drawing was used by the coordinategraph operator to produce a precision graph operator to produce a precision artwork master pattern on glass plate, 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 was 200x final size. At the next stage the P<sub>l</sub> was photographically reduced on a large precision reduction duced on a large precision reduction type camera (Ref. 1) to make a glass type camera (Ref. 1) to make a glass plate commonly called the first re-plate commonly called the first reduction or "reticle," a P2 glass duction or "reticle," a ?2 glass plate, at 20 x final size. These plate, at 20 x final size. These first reductions were placed in the first reductions were placed in the step and repeat camera and reduced step and repeat camera and reduced further as the camera stepped to pro-further as the camera stepped to produce the master mask or step photo duce the master mask or step photo by cut-and-peel techniques. The usual scale of the artwork master, or P, ,

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plate,  $P_3$ . Sets of  $P_3$ s, or  $P_4$  and  $P_5$  riag copies made from them by contact copies made from them by contact printing, are then used as photoengrav-printing, are then used as photoengraving stencils to define the areas to be ing stencils to define the areas to be worked on a silicon wafer, at each worked on <sup>a</sup>silicon wafer, at each state in the process of making an state in the process of making an array of semiconductor devices on the array of semiconductor devices on the wafer. wafer.





## 1.1 Design Goals 1.1 Design Goals

In 1961 when this system was In 1961 when this system was being set up, contact printed working being set up, contact printed working masks were usually of poor quality, masks were usually of poor quality, and therefore the  $P_3$ s themselves were  $\qquad$  ting used as working masks. This practice used as working masks. This practice led us to choose a step and repeat led us to choose a step and repeat camera design with a great many lens camera design with a great many lens barrels so that a great many P3s could be made at once; a camera with could be made at once; a camera with 12 barrels, or channels, was decided 12 barrels, or channels, was decided upon. upon.

Initially, the overall perfor-Initially, the overall performance goal of the camera was that the mance goal of the camera was that the stepped and repeated  $P_3$ s made on it should be capable of printing 2.5 micrometers (0.1 mil) lines, in regis-ter, when successive prints were made with different P3s. This goal sub-with different P3S. This goal subsumes all effects of lens resolution sumes all effects of lens resolution and optical distortion, magnification and optical distortion, magnification and focus errors, crooked camera ways, and focus errors, crooked camera ways, and all other error sources; but it the state allows trade offs. allows trade offs. should be capable of printing 2.5 micrometers (0.1 mil) lines, in regis-ter, when successive prints were made

#### 2.0 Optics 2.0 Optics

From the outset, it was realized From the outset, it was realized that this step and repeat camera that this step and repeat camera would be a developmental apparatus. would be a developmental apparatus. Not only would it produce microphoto-Not only would it produce microphotomasks for development of transistors masks for development of transistors and microcircuits, but the processes and microcircuits, but the processes and the camera would themselves be  $\frac{2}{3}$ subject to continuous change. In subject to continuous change. In essence the design became a vertical essence the design became a vertical optical bench, with a horizontal car-optical bench, with a horizontal car-

Coordinates are commonly large, or airborne, which riage for the final photoplates movable riage for the final photoplates movable in the plane of the image in X and Y in the plane of the image in X and <sup>Y</sup> coordinates. Prior experience with coordinates. Prior experience with optical reduction stepping printers optical reduction stepping printers for motion picture use led to immedi-for motion picture use led to immediate investigation of the probable ate investigation of the probable sources of defects in images. Table sources of defects in images. Table 2.1 summarizes the common contaminant 2.1 summarizes the common contaminant particle sizes likely to degrade or particle sizes likely to degrade or make unusable the images involved. make unusable the images involved. These contaminants were found to fall These contaminants were found to fall into the categories of glass chips into the categories of glass chips such as from the edges of the glass such as from the edges of the glass plates used; hair and skin flakes; and plates used; hair and skin flakes; and dust particles either settled, which dust particles either settled, which are on an average 5 microns. No conditions were observed which would ditions were observed which would cause upward projection of these parti-cause upward projection of these particles, and it was therefore decided cles, and it was therefore decided that it was good design to have the that it was good design to have the smallest image face down. An opaque smallest image face down. An opaque particle that falls upon the smallest particle that falls upon the smallest image will be contact printed at lx, image will be contact printed at Ix, causing the maximum amount of damage; causing the maximum amount of damage; the same particle on the P<sub>2</sub> image will be projection printed at 20x re-will be projection printed at 20x reduction and will do minimum damage. duction and will do minimum damage. Throughout the use of this equipment, Throughout the use of this equipment, we never found any evidence to contra-we never found any evidence to contradict this basic design assumption, but dict this basic design assumption, but we were always careful to avoid set-we were always careful to avoid setting up convective or turbulent air ting up convective or turbulent air currents in the camera room. currents in the camera room. are commonly large, or airborne, which are on an average 5 microns. No con-

# Table 2.1 Table 2.1 Common Particle Contaminants Common Particle Contaminants



It was observed that choosing the re-It was observed that choosing the reduction ratio became a trade -off prob-duction ratio became a trade-off problem as a means of matching the modu-lem as a means of matching the modulation transfer requirements, imaging lation transfer requirements, imaging of foreign particle contamination, and of foreign particle contamination, and making of the P<sub>2</sub> plates. A survey of the commercially available objective the commercially available objective lenses and plates suitable for the 200 lenses and plates suitable for the 200 line pairs per millimeter spatial fre-line pairs per millimeter spatial frequency goal led us to selection of a quency goal led us to selection of <sup>a</sup>  $20x$  reduction ratio from the P<sub>2</sub> to the  $P_3$ , with the plate characteristics shown in Table 2.2 shown in Table 2.2

Table 2.2 Table 2.2 Plates Plates



As 20x reduction is close to in-As 20x reduction is close to infinity correction of the geometric finity correction of the geometric optics of such objectives, we found  $\qquad \quad \, 1\bar{2}$ that a selected and closely matched that a selected and closely matched group of double gauss objectives as group of double gauss objectives as described in Table 2.3 was available described in Table 2.3 was available for the 12 lenses required for the 12 for the 12 lenses required for the 12 barrel camera. We bought them. The barrel camera. We bought them. The General Scientific Company tests of General Scientific Company tests of their SOLMAR double gauss microfilm th type lenses indicate the limit of re-type lenses indicate the limit of resolution feasible. In optical bench solution feasible. In optical bench tests, and in subsequent use of these tests, and in subsequent use of these objectives in the camera, we achieved objectives in the camera, we achieved our goal of being able to make .10 mil our goal of being able to make .10 mil lines (2.5 microns). (Note that this lines (2.5 microns). (Note that this is not identical with white lines in is not identical with white lines in dark backgrounds.) dark backgrounds.)

# Table 2.3 Table 2.3 Objectives Objectives



\*per supplier \*per supplier

Because the 12 lenses were not Because the 12 lenses were not of identical focal lengths, although of identical focal lengths, although within the manufacturer's tolerance of within the manufacturer's tolerance of +2 %, it was not possible to design the +2%, it was not possible to design the  $\overline{\text{c}}$ amera with all P $_2$  images in one plane  $\quad$  cular and all P<sub>3</sub> images in another; the magnification differences between channels nification differences between channels would have been unacceptable. A single **would** have been unacceptable. A single flat surface with openings and mechani-flat surface with openings and mechani-

320 lines/MM2MM off Axis removed and a lens support bracket was cal clamping of the glass plates for cal clamping of the glass plates for P3 holding was tested. This requires ?3 holding was tested. This requires  $12$  separate plates for  $P_2$  images. Individual holders for  $\bar{\text{P2}}$  plates for each channel requires ea $\bar{\text{c}}$ h such P $_2$  to be aligned separately and very pre-be aligned separately and very precisely. The second construction for cisely. The second construction for matching magnifications places matching magnifications places all P2 images in one plane and varies all P2 images in one plane and varies the distance to each P3 for magnification control. This was found to have tion control. This was found to have advantages beyond the uniformity of advantages beyond the uniformity of magnification; accordingly, the camera magnification; accordingly, the camera was designed to have a single P2 plate, was designed to have a single ?2 plate, with 12 adjustable lens mounts and 12 with 12 adjustable lens mounts and 12 adjustable P3 holders. The mounting adjustable ?3 holders. The mounting of the objectives, focus, and magnifi-of the objectives, focus, and magnification control posed basic design de-cation control posed basic design decisions. The choice appeared to be cisions. The choice appeared to be between complete precision design and between complete precision design and a simple adjustable construction a simple adjustable construction allowing great variability. As we had allowing great variability. As we had then no knowledge of the variations then no knowledge of the variations eventually to be required in the equip-eventually to be required in the equipment, initial experiments used the ment, initial experiments used the barrel lens mount adapted to fit a barrel lens mount adapted to fit a fine -focus Bausch and Lomb microscope fine-focus Bausch and Lomb microscope barrel assembly (part No. 31 -29- 0301). barrel assembly (part No. 31-29-0301). The microscope tube caused vignetting, The microscope tube caused vignetting, and so when subsequent developments and so when subsequent developments required elimination of vignetting for required elimination of vignetting for a better field of view, the tube was a better field of view, the tube was fitted to the focusing mechanism. The fitted to the focusing mechanism. The fine focus microscope assembly proved fine focus microscope assembly proved quite desirable because of its straight-quite desirable because of its straightline translation, without dependence line translation, without dependence on screw threads or sliding sleeve on screw threads or sliding sleeve fits for linear translation in focus fits for linear translation in focus of the objective; however, it did not of the objective; however, it did not provide for initial adjustment of the provide for initial adjustment of the optical axis of the objective perpendi-optical axis of the objective perpendicular to the photo plate. For this we cular to the photo plate. For this we designed a ball mount shown in Fig.2.1 designed a ball mount shown in Fig.2.1 which rotates the objective around the which rotates the objective around the nodal point without changing other nodal point without changing other parameters. This simple two -piece axis parameters. This simple two-piece axis

rotation construction slides on the rotation construction slides on the spherical ball surface for coarse set-spherical ball surface for coarse settings, and apparently sets finally by tings, and apparently sets finally by minor flexure. It should be noted minor flexure. It should be noted that because the Bausch and Lomb fine that because the Bausch and Lomb fine focus assemblies were used inverted focus assemblies were used inverted from their designed position, spring from their designed position, spring pressure gravity compensators were re-pressure gravity compensators were required. Friction clamps were found quired. Friction clamps were found necessary on both coarse and fine necessary on both coarse and fine motions. motions.



# Figure 2.1 Figure 2.1 Ball Mount Ball Mount

The basic optics for one of the The basic optics for one of the 12 barrels or channels of the camera 12 barrels or channels of the camera are shown in Fig. 2.2 and consist of are shown in Fig. 2.2 and consist of a single light source common to all <sup>a</sup>single light source common to all channels, a condensing lens, the first channels, a condensing lens, the first reduction photo plate P2, the object-reduction photo plate P2, the objective, and finally the image  $P_3$ . We  $\qquad \qquad \overline{\qquad \qquad }$ folded the systems between the lamp folded the systems between the lamp and the condenser, as shown in Fig. and the condenser, as shown in Fig. 2.3. The fold mirrors are plate 2.3. The fold mirrors are plate glass but viewed as a group they glass but viewed as a group they approximate an off -axis parabola. approximate an off-axis parabola.

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

Initially the camera was set up Initially the camera was set up to make masks on lx3 inch microscope - to make masks on 1x3 inch microscopeslide sized photoplate (Fig. 2.4). slide sized photoplate (Fig. 2.4). This was the size commonly used by the This was the size commonly used by the the semiconductor industry at that the semiconductor industry at that



Figure 2.2 Figure 2.2 Basic Optics Basic Optics



Figure 2.3 Figure 2.3 Folded Construction, Folded Construction, Single Lamp Single Lamp

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time, when a silicon wafer threequarters of an inch in diameter was quarters of an inch in diameter was considered enormous. But we found considered enormous. But we found that during processing of the photoplate the influence of the edge of the plate the influence of the edge of the plate can produce such dimensional plate can produce such dimensional shifts that precise registration be-shifts that precise registration became uncertain at the edge of a .625 came uncertain at the edge of a .625 inch diameter array. Accordingly, inch diameter array. Accordingly, the camera was changed to make P3s on 2x2 inch photoplate. 2x2 inch photoplate.



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

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

## 3.0 First Reduction Plates 3.0 First Reduction Plates

When all  $P_2$  images are placed upon one photoplate of glass as shown upon one photoplate of glass as shown in Figure 3.1, it becomes practical in Figure 3.1, it becomes practical to place on this plate a single pair to place on this plate a single pair of fiducial alignment marks. These of fiducial alignment marks. These marks, shown as crosses on Figure 3.1, marks, shown as crosses on Figure 3.1, are spaced roughly 12 inches apart. are spaced roughly 12 inches apart. This allows aligning all  $12$  P<sub>2</sub> patterns simultaneously, a great labor terns simultaneously, a great labor saving. Obviously the 12 inch dis-saving. Obviously the 12 inch distance between fiducial marks is an tance between fiducial marks is an optical lever 4 to 6 times more effec-optical lever 4 to 6 times more effective than any to be had on a 2 to 3 tive than any to be had on a 2 to 3 inch  $P_2$  plate. With this leverage,  $the$ two 20x macroscopes equipped with s reticle eyepieces allow manual orien-reticle eyepieces allow manual orientation and placing of the  $P_2$  plate  $P_1$ in the camera holder. No auxiliary 11 pho alignment equipment is required under alignment equipment is required under



Figure 2.5 Figure 2.5 2x2 Inch Mask 2x2 Inch Mask



## Figure 3.1 Figure 3.1 First Reduction Plate First Reduction Plate (12 Channel) (12 Channel)

these conditions. Implicit in this 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 photoplate at the time of exposure (Ref. 1). (Ref. 1). system of a  $12$ -channel  $P_2$ , is the necessity of placing all patterns in pro

Upon use of the unitary 12 -chan-Upon use of the unitary 12-channel construction, it was found that nel construction, it was found that the fixed location of each channel on the fixed location of each channel on the P $_{2}$  led to the capability of selecting which type of artwork would lecting which type of artwork would go into which channel, thereby allow-go into which channel, thereby allowing assignment of the most critical ing assignment of the most critical artwork to the best -performing chan-artwork to the best-performing channel. It should be noted that in the nel. It should be noted that in the early development of this camera, early development of this camera, when only four channels had been built, when only four channels had been built, the initial use of the unitary P<sub>2</sub> was trail with 8x10 inch glass photoplates, and with 8x10 inch glass photoplates, and the size was subsequently expanded the .size was subsequently expanded for the 12 channel system. for the 12 channel system.

In a later shakedown of toler-In a later shakedown of tolerances of operation of the camera, the ances of operation of the camera, the holder for the P<sub>2</sub> plate was upgraded year from a simple friction slot holder. from a simple friction slot holder. Vacuum pockets were milled into the Vacuum pockets were milled into the reference surface of the holder frame, reference surface of the holder frame, working on the emulsion surface (up) working on the emulsion surface (up) of the P2 as the positioning clamp of the P2 as the positioning clamp after  $P_2^-$ alignment. When the camera  $\quad$  in F needed correcting, the holder fráme needed correcting, the holder frame could be adjusted by 3 micrometer could be adjusted by 3 micrometer screw constructions to provide coarse screw constructions to provide coarse positioning prior to final position-positioning prior to final positioning of the P3 system.

## 4.0 Mask Plates 4.0 Mask Plates

The photographic glass upon The photographic glass upon which the emulsion is coated, for use which the emulsion is coated, for use in this type of apparatus, is commonly in this type of apparatus, is commonly a select grade of glass. For the  ${\tt P2}$  ast plates our experience was that devia-plates our experience was that deviation from flatness fell roughly around tion from flatness fell roughly around 1 mil per inch, and the 2x2 inch high 1 mil per inch, and the 2x2 inch high resolution photographic plates were resolution photographic plates were better than the  ${\tt P_2}$  glass, sometimes 0.5 mil per inch departure from flatness. (2x2 inch plates used on this camera were .060 inches thick.) Thus camera were .060 inches thick.) Thus the departure from flatness on the P $_{\rm 2}$ between the vacuum rails 7 inches between the vacuum rails 7 inches apart, could as a limit be 7 mils. apart, could as a limit be 7 mils. The vacuum rail serves as a go -no go The vacuum rail serves as a go-no go gauge for flatness along the 18 inch gauge for flatness along the 18 inch dimension and will not retain vacuum dimension and will not retain vacuum holding if the photo plate does not holding if the photo plate does not come flat against the rail, thus re-come flat against the rail, thus rejecting automatically any plate de-jecting automatically any plate departing excessively in flatness along parting excessively in flatness along the longer dimension. As the relative the longer dimension. As the relative aperture on the P<sub>2</sub> side of the objectives makes the system tolerant of ives makes the system tolerant of small errors in depth of focus, outof- flatness is not critical to image of-flatness is not critical to image quality, the effect being confined to quality, the effect being confined to magnification error. magnification error. better than the  $P_2$  glass, sometimes 0.5 mil per inch departure from flatness. (2x2 inch plates used on this

It can be shown theoretically It can be shown theoretically that the out-of-flat  $P_2$  is capable of the making a 2/10th mil P<sub>3</sub> error which is tion quite significant, when it is quite significant, when it is

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

Flatness of P<sub>3</sub> glass has similar problems. A vacuum clamp ring in the problems. A vacuum clamp ring in the plate holder was constructed as shown plate holder was constructed as shown in Figure 4.1. A vacuum channel was in Figure 4.1. A vacuum channel was cut in a ring which was lapped and cut in a ring which was lapped and potted in place in the carriage which potted in place in the carriage which could be leveled and moved up and down could be leveled and moved up and down by micrometer thimbles for magnifica-by micrometer thimbles for magnification correction. As with the P<sub>2</sub>, loss of P<sub>3</sub> vacuum indicates unacceptably out -of -flat plates, and the vacuum will out-of-flat plates, and the vacuum will pull in plates which depart only pull in plates which depart only slightly from flatness. With the 1.25 slightly from flatness. With the 1.25 inch diameter opening in the P3 holder inch diameter opening in the PS holder last installed in the camera, depart-last installed in the camera, departures from the ideal focus plane were ures from the ideal focus plane were minimized to the wafer size in use at minimized to the wafer size in use at that time. that time.



Figure 4.1 Figure 4.1 P<sub>3</sub> Holder (Three point levelled lapped (Three point levelled lapped vacuum ring hold down) vacuum ring hold down)

The effect of out of flatness in The effect of out of flatness in the P3 plane is a change of magnifica-the PS plane is a change of magnification of the entire pattern, not of tion of the entire pattern, not of only one side as in the case of P2 only one side as in the case of P2

errors. Thus if a P<sub>3</sub> plate bulges bu upward it then produces a larger upward it then produces a larger image over the entire device, but as image over the entire device, but as the exposures step to the edge of the the exposures step to the edge of the plate they come nearer to the ideal plate they come nearer to the ideal plane and nearer to the normal size. plane and nearer to the normal size. For a semiconductor device of 2x2 For a semiconductor device of 2x2 milimeter die size (80x80 mils) a milimeter die size (80x80 mils) <sup>a</sup> magnification change amounting to magnification change amounting to 1.25 microns (.05 mils) can result; 1.25 microns (.05 mils) can result; however, when this is closer to the however, when this is closer to the objective than the ideal focus, the objective than the ideal focus, the thickness of the photographic emul-thickness of the photographic emulsion of about 6 micrometers has a sion of about 6 micrometers has <sup>a</sup> tendency to reduce the shrink slightly. tray

In order to minimize the effects In order to minimize the effects of glass flatness when adjusting mag-of glass flatness when adjusting magnification and registration of the nification and registration of the step and repeat camera, it is desir-step and repeat camera, it is desirable to use a  ${\tt P}_2$  plate made of plate  $~\,$  leng glass or a selected piece flatter glass or a selected piece flatter than the normal glass, and similarly than the normal glass, and similarly on the  $\texttt{P}_3$ .

# 5.0 Registration 5.0 Registration

The registration goal of this The registration goal of this step and repeat camera was chosen as step and repeat camera was chosen as being suitable for production of geo-being suitable for production of geometry with 2.5 micrometer lines. It metry with 2.5 micrometer lines. It was assumed that  $\frac{1}{2}$  (l.25 micrometers) was a limit that could be achieved. was <sup>a</sup>limit that could be achieved. Thus the total stack deviation con-Thus the total stack deviation considered allowable as a registration sidered allowable as <sup>a</sup>registration contribution is 1.25 micrometers. The contribution is 1.25 micrometers. The effects of glass flatness have been effects of glass flatness have been treated above. In the selected lenses treated above. In the selected lenses no effects of variation in distortion no effects of variation in distortion of geometrical optical character were of geometrical optical character were detected. With the ball mount lens detected. With the ball mount lens corrections for mechanical mount corrections for mechanical mount alignment, tilted axes were corrected alignment, tilted axes were corrected to the point where keystone errors to the point where keystone errors were not measurable in this system. were not measurable in this system. The remaining sources of registration The remaining sources of registration error to be discussed are the ways error to be discussed are the ways and the stepping system. and the stepping system.

The original set of ways pur-The original set of ways purchased for the developmental studies chased for the developmental studies were hand scraped. The equipment was were hand scraped. The equipment was built and used in a clean room; ini-built and used in a clean room; initially this was approximately NASA tially this was approximately NASA class 500, and finally NASA equiva-class 500, and finally NASA equivalent of class 50. Apparently, the lent of class 50. Apparently, the cleaner the room, the fewer the par-cleaner the room, the fewer the particles deposited in the lubricants to ticles deposited in the lubricants to form a slurry, and the sooner the up-form a slurry, and the sooner the upsets of the hand scraping alignment sets of the hand scraping alignment ceased to lubricate, galled, and went ceased to lubricate, galled, and went out of straightness. Efforts to locate improved lubricants were futile, cate improved lubricants were futile, as the lubricants either spread over as the lubricants either spread over the optics, or failed to lubricate. the optics, or failed to lubricate. A second set of ways, of relatively <sup>A</sup>second set of ways, of relatively superior quality, was purchased, but sency

but it was found they exhibited two but it was found they exhibited two peaks. By autocollimation these were peaks. By autocollimation these were found to be upsets produced by the found to be upsets produced by the manufacturer, who had drilled the mount manufacturer, who had drilled the mount positions through the ways subsequent positions through the ways subsequent to precision grinding of the bearing to precision grinding of the bearing surfaces. surfaces.

The departure from theoretical The departure from theoretical conditions of straight ways and its conditions of straight ways and its influence on registration will be aided influence on registration will be aided by Figure 5.1. This schematic uses a by Figure 5.1. This schematic uses <sup>a</sup> line as the X ways and another at a line as the X ways and another at <sup>a</sup> right angle to that as the Y ways. right angle to that as the Y ways. The Y ways are hitched to a schematic The Y ways are hitched to a schematic tray bearing the 12 P3s. The distance y from the X ways is shown to the cen-y from the X ways is shown to the center of the tray. The horizontal rota-ter of the tray. The horizontal rotational angle from the centers theta tional angle from the centers theta induces delta X as shown. The radius induces delta X as shown. The radius length on theta to channel 7 is rough-length on theta to channel 7 is roughly 370 millimeters, at the end of which ly 370 millimeters, at the end of which registration is sought to 1 micrometer registration is sought to 1 micrometer roughly. This corresponds to 0.6 roughly. This corresponds to 0.6 seconds of arc. seconds of arc.



# Figure 5.1 Figure 5.1 Registration Effect Registration Effect of Ways Deviation of Ways Deviation

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

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

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

## 7.0 Discussion 7.0 Discussion

At the camera's last inventory late in 1971, it was found that of the late in 1971, it was found that of the original camera as designed, besides original camera as designed,besides the objective lenses, only one frame the objective lenses, only one frame and two other original parts remained and two other original parts remained in the final camera. The frame is in the final camera. The frame is that supporting the mirror segments that supporting the mirror segments and the parts are the granite base and and the parts are the granite base and column with the toolmakers angle plate column with the toolmakers angle plate mounted thereupon. Mounted on the  $P_3$ plate carriage assembly will be seen plate carriage assembly will be seen on top of camera a stage carrying a on top of camera a stage carrying <sup>a</sup> plate upon which there is a glass plate upon which there is a glass bearing a diamond ruled grid (Fig. bearing a diamond ruled grid (Fig. 7.1). This is illuminated by a micro-7.1). This is illuminated by a microscope using a lamp at the eyepiece scope using a lamp at the eyepiece "exit" pupil. This lighting matches "exit" pupil. This lighting matches the viewing microscope twin, which the viewing microscope twin, which projects the grid upon a rear- projec-projects the grid upon a rear-projection screen for microscope viewing tion screen for microscope viewing (commercial item). On the round viewing screen a number of geometries ing screen a number of geometries have been used experimentally. A have been used experimentally. <sup>A</sup> simple cross line is satisfactory pro-simple cross line is satisfactory providing its exact center is missing. viding its exact center is missing. By motion of the X and Y cranks, the con image on the microscope screen will be image on the microscope screen will be shifted from one intersection to the shifted from one intersection to the next for the exposure when the car-next for the exposure when the carriage is at rest, and the torque on The the drive screws relaxed. By use of the positional location by reference to a positional location by reference to <sup>a</sup> ruled grid such variables as the grease trun wandled and the such variables as the grease on the screw threads, the differences on the screw threads, the differences between operators, and wear, are no between operators, and wear, are no longer of influence; and positions are ing t repeatable within reasonable limits of sive vision. vision.

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

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



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

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

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

## 7.2 Interconnection Patterns 7.2 Interconnection Patterns

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

## 7.3 Automation 7.3 Automation

By selection of photocell sensi-By selection of photocell sensitivity and the color of the pattern tivity and the color of the pattern placed over the microscope viewing placed over the microscope viewing screen, integration of the light pass-screen, integration of the light passing through the trigger slit to the ing through the trigger slit to the photocell was used to activate pulse photocell was used to activate pulse illumination in place of the enlarg-illumination in place of the enlarging lamp normally used for exposure. ing lamp normally used for exposure. For these tests the camera was For these tests the camera was equipped with a bead chain motor drive equipped with a bead chain motor drive on the X and Y axis also. These were on the X and Y axis also. These were controlled manually in the feasibility controlled manually in the feasibility tests. As pulsed exposure occurred at tests. As pulsed exposure occurred at each intersection of the ruled grid, each intersection of the ruled grid, no counting logic was required. How-no counting logic was required. However, it must be mentioned that it is ever, it must be mentioned that it is necessary to make a different ruled necessary to make a different ruled grid for each step and repeat raster. grid for each step and repeat raster. During the tests the operator spent During the tests the operator spent most of his labor returning the camera most of his labor returning the camera to the next line, as the automated a axis did not position satisfactorily axis did not position satisfactorily for a stop. In the previously dis-for a stop. In the previously discussed information on registration, it cussed information on registration, it will be seen that the requirements are will be seen that the requirements are quite demanding. While feasibility in principle was clearly demonstrated in principle was clearly demonstrated in automation, the vibration and flexure automation, the vibration and flexure destroyed the quality of the mask, and  $\frac{1}{2}$  and  $\frac{1}{2}$ the automation system was removed. the automation system was removed.

## 7.4 Housing 7.4 Housing

The room in which the camera was  $\frac{1119}{10}$ placed was provided in its final form placed was provided in its final form with a very excellent air handling  $\frac{1}{r}$ system which maintained excellent tem-system which maintained excellent temperature control and contaminating perature control and contaminating particle control; however, this did particle control; however, this did not eliminate other hazards. One not eliminate other hazards. One workman put his foot through the ceil-workman put his foot through the ceiling from above and nearly destroyed ing from above and nearly destroyed the camera. On another occasion, an the accident in the epitaxial reactor area summer  $\frac{c}{sin}$ flooded the room with corrosive mater-flooded the room with corrosive materials. Consequently, a housing was ials. Consequently, a housing was built for the camera which totally built for the camera which totally enclosed it and which was closed when-enclosed it and which was closed whenever the camera was not in use. It  $\frac{0}{1}$ was also found that this housing had a  $\frac{10}{100}$  ing. tendency to integrate the variations tendency to integrate the variations in temperature control which occurred in temperature control which occurred

during power outages, thus increasing during power outages, thus increasing the productive time availability of the productive time availability of the apparatus. the apparatus.

# 7.5 Operation and Service 7.5 Operation and Service

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

## Conclusions Conclusions

## 8.1 Optical Limits 8.1 Optical Limits

In the equipment described, it In the equipment described, it was not anticipated at the outset that was not anticipated at the outset that devices of the size finally sought devices of the size finally sought would be required, and the optical would be required, and the optical centerline to optical centerline spac-centerline to optical centerline spacing of 3.0 inches limited the size of ing of 3.0 inches limited the size of the die size on the P<sub>3</sub>. The objective lens was capable of larger size, but lens was capable of larger size, but reconstruction of the equipment at the reconstruction of the equipment at the near end of useful production time was near end of useful production time was not merited. not merited.

The use of a single lamp for ex-The use of a single lamp for exposure of all channels introduces uni-posure of all channels introduces uniformity of exposure, both a blessing formity of exposure, both a blessing and a curse. The problem arises from and a curse. The problem arises from the difficulty with lines near the the difficulty with lines near the limits of the system which on occasion limits of the system which on occasion require more exposure. It was origin-require more exposure. It was originally planned that neutral density fil-ally 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 mask-to correct for this, if unsharp masking were not used. ing were not used.



# Table 7.5 Table 7.5 Configuration Performance Configuration Performance

## 8.2 X-Y Ways

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

## 8.3 Reduction Ratios 8.3 Reduction Ratios

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

# 8.4 Fixed versus Adjustable Design 8-4 Fixed versus Adjustable Design

Of the basic mechanical compon-Of the basic mechanical components, only the X-Y ways were commercial products, the rest being manu-cial products, the rest being manu-

factured in our machine shop without factured in our machine shop without high precision requirements. As the high precision requirements. As the camera room was temperature stabil-camera room was temperature stabilized, the use of aluminum for major ized, the use of aluminum for major structural elements was tolerated as structural elements was tolerated as an expedience. This was a satisfact-an expedience. This was a satisfactory compromise on materials for the ory compromise on materials for the performances sought in the original performances sought in the original apparatus, but no longer acceptable apparatus, but no longer acceptable by present step and repeat camera re-by present step and repeat camera requirements. Hysteresis effects of quirements. Hysteresis effects of temperature variations, changes in the temperature variations, changes in the character of photomaterials, and main-character of photomaterials, and maintenance requirements convince one that tenance requirements convince one that the necessity for adjustive construc-the necessity for adjustive construction is essential for the optical tion is essential for the optical photograph train of a step and repeat photograph train of a step and repeat camera. The micrometer thimbles for camera. The micrometer thimbles for leveling the P3 holders were settable only with great difficulty to the re-only with great difficulty to the required tolerances. The fine -focus quired tolerances. The fine-focus microscope bodies gave less trouble. microscope bodies gave less trouble. Autocollimation and laser alignment Autocollimation and laser alignment techniques did not prove of great techniques did not prove of great value in the most important qualities value in the most important qualities of registration. of registration.

# 8.5 Dedication 8.5 Dedication

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



1. Granite column Granite column

- 2. Light source Light source
- 3. Fold mirrors Fold mirrors
- 4. Box Box
- 5. Condensing lenses Condensing lenses
- (Squared, in frame) (Squared, in frame) 6. Fiducial mark lamp Fiducial mark lamp
- $Box P_2$
- 7. Box  $P_2$ 8. Macroscope alignment P2 fiducial marks Macroscope alignment P<sub>2</sub> fiducial marks
- 9. P2 levelling jack P<sub>2</sub> levelling jack
- 10. P2 plate P<sub>2</sub> plate

2

- 11. Box, objective lens Box, objective lens assemblies assemblies
- 12. Ball mount lens Ball mount lens aligners aligners
- 13. Objective lens Objective lens
- 14. Box,  $P_3$ 12 separate carriers 12 separate carriers magnification and magnification and level adjustments level adjustments
- 15. Hand cranks X and Y Hand cranks X and Y ways ways
- 16. Ruled grid plate and Ruled grid plate and carrier carrier
- 17. X and Y grid compar-X and Y grid comparator ator

Figure 8 Figure 8 Step and Repeat Camera Step and Repeat Camera Final Configuration (Museum) Final Configuration (Museum) years. The museum also has a quantity years. The museum also has a quantity of masks made on the camera. (Fig. 8) of masks made on the camera. (Fig. 8)

## 9.0 Acknowledgements 9.0 Acknowledgements

Design responsibility for the Design responsibility for the step and repeat camera was the authors step and repeat camera was the authors with management assistance by Dr. Jay with management assistance by Dr. Jay T. Last. Machining and subsequent T. Last. Machining and subsequent modifications by Michael Challis. modifications by Michael Challis. Melvin Wright devised alignment and Melvin Wright devised alignment and control apparatus and procedures. A control apparatus and procedures. A number of special fittings and instru-number of special fittings and instrumentation were made by Charles Kilet. mentation were made by Charles Kilet. Lee K. Yamada also devised a number of Lee K. Yamada also devised a number of improvements. All of the above at improvements. All of the above at various times operated the camera for various times operated the camera for production of master P3 mask sets. production of master ?3 mask sets. Patricia Clow contributed critical Patricia Clow contributed critical analysis of the parameters. We must analysis of the parameters. We must also acknowledge the very useful gen-also acknowledge the very useful general suggestions by Eugene Troyer, eral suggestions by Eugene Troyer, and many others too numerous to men-and many others too numerous to mention. tion.

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