

PATENT SPECIFICATION

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DRAWINGS ATTACHED

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(54) A METHOD OF AND APPARATUS FOR LIGHT-WRITING MASK PATTERNS

(71) We, PHILIPS ELECTRONIC AND ASSOCIATED INDUSTRIES LIMITED, of Abacus House, 33 Gutter Lane, London, E.C.2., a British Company, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

10 The invention relates to a method of writing mask patterns on a photographic material by means of light, in which method a spot of light is formed from the light of a source of light by means of an opening which in principle is rectangular, said light spot being moved over the photographic material along paths which correspond to the mask patterns to be written.

20 The invention also relates to an apparatus for writing mask patterns on a photographic material by means of light. The term "light" is used herein to mean an electromagnetic oscillation having a wavelength between 0.2 μm and 2 μm .

25 In the manufacture of integrated circuits and large-capacity stores photomasks are used. Since the masks have to satisfy exacting requirements in respect of their dimensions, in the manufacture of photomasks patterns of these masks are first drawn to an enlarged scale with a high degree of accuracy and subsequently reduced to the desired size by photographic means.

35 In a known method, see for example the article "Mask Manufacture for Integrated Circuits" in "The Western Electric Engineer", Vol XI, No. 4, pages 35—37, the desired pattern is first cut by a numerically controlled drawing machine in the upper layer of a two-layer plastics foil of, say, 40 120×120 cm². After the upper layer has been locally peeled off, i.e. after the opaque material within the contours cut has been removed, the pattern is reduced, say, 30 times with a fixed camera arrangement. Then the resulting mask pattern is further reduced, for example 10 times, in a step-and-repeat

camera, a large number of images being successively formed in different areas of a photographic plate, so that a large number of equal mask patterns of the desired size are produced on this plate.

The only non-automatized stage of this method is the local peeling of the opaque upper layer of the plastics foil, which operation demands a high degree of accuracy and takes much time. Peeling requires far more time than drawing. The above process further requires a large room.

By writing the initial mask patterns by means of light instead of cutting them from a plastics foil the following advantages are obtainable:

- 1). the non-automatized peeling stage may be dispensed with, so that:
 - a) much time can be saved in the manufacture of photomasks,
 - b) no errors due to incorrect peeling of the plastics foil, occur in the finished photomasks;
- 2). the size of the initial large written pattern may be greatly reduced with an equal or even improved final accuracy, so that
 - a) no intermediate reduction is required,
 - b) the time required for writing the first large pattern can be reduced by a factor of, say, 10.

The pattern elements of the mask pattern to be written must have a prescribed width throughout their length. The location of the transition from black to transparent along a path depends upon the location of the transition between light energy and no light energy, but also, because this transition is indistinct in practice, upon the amount of the light energy. The point at which in a transition from transparent to black a density 2 is obtained depends upon the point at which in this transition an exposure energy associated with the density 2 is found. If the location of the transitions from black to transparent along a path is to be controlled, the exposure energy must be controlled. The exposure energy depends upon the intensity of illu-

mination on the photographic material and upon the exposure time.

For writing by means of light one may start from either of two principles. According to the first principle, the photographic material may be exposed by means of a light spot which is stationary relative to the material or by means of a quasi-stationary light spot, by exposing with a light pulse of very short duration whilst moving the material. According to the second principle the photographic material may be exposed by means of a light spot which essentially moves relative to the material.

In exposure by means of a stationary light spot there are in principle no difficulties in maintaining a constant exposure energy. Exposure in the stationary condition is described *inter alia* in "advances in Computer Generation of Master Artwork for Micro-miniature Circuits", S.C.P. and Solid State Techn. (Vol. 10, 7 July 1967, pages 31—34). This method has the disadvantage that the obtainable latitude in the form or design of a mask pattern is very limited. In view of the time required to build the entire mask pattern, in this method the mask pattern must be built from a comparatively limited number of rectangles.

With continuous exposure during constant velocity movement of the light spot relative to the photographic material, the exposure time T is given by $T = l'/v$, where l' is the length of the light spot in the direction of writing and v is the writing velocity. However, without special expedients T will assume an undesirable value owing to the accelerations and decelerations (i.e. increasing and decreasing v) which occur at the beginning and at the end respectively of a line being written. The consequent undesirable effects can be eliminated partly only by adaptation of the intensity of illumination.

The paper "Microcircuit Photomasks from Automatic Techniques" in "IEEE Transactions on Electron Devices", vol. ED-12, No. 12, Dec. 1965 p. 638—643, describes a method of writing photomasks by means of a moving light spot in which a solution of this difficulty is given. A light spot of a length which in principle is constant is swept over the photographic material at a velocity which in principle is uniform. At point at which no exposure is desired, the light spot is blocked by a shutter. At a point at which a pattern element is to begin or to end the shutter is moved so that the transition light-dark in the light spot will be temporarily stationary relative to the photographic material. Thus, a constant exposure energy per unit area is obtainable throughout the entire length of a pattern element to be written. To obtain a satisfactory image quality exposure takes place in projection. The opening defining the light spot and the

shutter both form part of the projection system, and a reduced image of them is formed by this system. The projection system as a whole moves relative to the photographic material. At the beginning and at the end of a pattern element a movement of the shutter relative to the opening defining the light spot is to be effected with a high degree of accuracy, and this movement must match the speed of the projecting system as a whole relative to the photographic material. Matching errors may readily slip in during the complicated controlling process and they will result in incorrect locations of the beginning and the end of a pattern element. Further, a large disadvantage is that accelerations and decelerations of the spot of light relative to the photographic material occur outside the line segment, and this takes additional time.

According to the present invention in a method of writing mask patterns on a photographic material by means of light, in which a spot of light is formed from the light of a source of light by means of an opening which is substantially rectangular, and in which said light spot is moved relative to the photographic material along paths which correspond to the mask patterns to be written, the length of the light spot in the direction of writing is determined by two boundaries which are separately controlled so that for each infinitesimal element of a pattern element to be written the time elapsing between the passage of the initial boundary of the light spot and the passage of the final boundary of the light spot over the infinitesimal element is the same, irrespective of accelerations or decelerations in the relative movement of the light spot and the photographic material. Thus the exposure time is equal for each infinitesimal element. With the use of a constant intensity of illumination the exposure energy also will be the same for each infinitesimal element of the pattern element being written.

According to a further feature of the method according to the invention, the width of the light spot at right angles to the direction of writing is determined by two adjustable transverse boundaries situated at least substantially in the plane containing the initial and final boundaries.

The initial and final boundaries and the transverse boundaries may be spaced from the photographic material by a very small distance. However, it is more advantageous to dispose all the boundaries at some distance from the photographic material and to form reduced images of them by means of a lens system.

In an apparatus for carrying out the method according to the invention the initial and final boundaries are formed respectively by two knives which are arranged in the path of the light from the light source to the

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photographic material present during the writing process, during which process one of the knives is stationary with respect to a lens system which forms the light spot, and the other is movable with respect to this lens system.

In a preferred embodiment of an apparatus according to the invention, the transverse boundaries are constituted by one of a number of transparent areas of different lengths provided in the radial direction in an opaque disc which is rotatable about an axis at right angles to the plane of the disc.

In a further preferred embodiment of an apparatus for carrying out the method according to the invention there is arranged in the path of the light between the boundaries and the lens system a mirror system mounted in a rotatable drum so that the axis of rotation substantially coincides with the optical axis of the lens system. This permits writing in any desired direction. The mirror system may comprise a reflecting prism and a plane mirror.

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

Figures 1 and 2 illustrate the principle of the invention,

Figure 3 is a front elevation of the apparatus according to the invention, and

Figure 4 is a top plan view of the apparatus according to the invention taken on the line ZZ' of Figure 3.

Referring now to Figure 1, a photographic plate on which the mask patterns are to be written is designated 1. The x direction is the direction in which the light spot is swept over the photographic material. The photographic plate itself is displaceable in a direction y at right angles to the x direction, i.e. at right angles to the plane of the drawing in Figure 1. The light spot is bounded in the writing direction by "knives" A' and B'. These "knives" A' and B' are not material knives but they are the images of material knives A and B produced by a lens system 7 (see Figure 3).

The knife image A' is moved according to a function:

$$x_{A'} = f(t).$$

If now the knife image B' is moved relative to the knife image A' with a constant time lag τ and hence according to a function:

$$x_{B'} = g(t) = f(t - \tau)$$

the exposure time will be equal for the entire pattern element:

$0 \leq x \leq x_1$, where x_1 is the limit distance in the x -direction.

This may be appreciated from a considera-

tion of Figure 2 in which curves 2 and 3 show the paths travelled by the knife images A' and B' respectively as functions of time.

The function:

$$x_{A'} = f(t)$$

only has to satisfy the requirement of being continuous and of ascending monotonically in t . For an arbitrary point $x=a$, with $0 \leq a \leq x_1$, we have at the beginning of the exposure:

$$f(t_{\text{beginning}}) = a \quad (1)$$

and for the end of the exposure:

$$g(t_{\text{end}}) = f(t_{\text{end}} - \tau) = a \quad (2)$$

From (1) and (2) it follows:

$$t_{\text{end}} - t_{\text{beginning}} = \tau.$$

Consequently, the exposure time ($t_{\text{exposure}} = t_{\text{end}} - t_{\text{beginning}}$) is constant for each $0 \leq x \leq x_1$ and equal to τ .

The writing of each image element can be carried out starting with stationary boundaries, which is important for the total writing time required and for the number of possible mask patterns that can be written.

The method according to the invention may be carried out by means of an apparatus as shown in Figure 3. In the apparatus of Figure 3, light from a source of light 4 is concentrated on to one of a number of slits in a disc 6 by a condenser 5. After passing through this slit the light beam passes through the opening between the material knives A and B located close to the disc 6. The knives A and B and the part of the respective slit located between the knives are imaged by an objective 7; A' is the image of A and B' is the image of B.

Figure 4 is a top plan view of the disc 6 and of the knives A and B viewed according to the line Z-Z' of Figure 3. The disc is provided with radial slits S of different lengths. By rotating the disc one of the slits is lined up with the knives A and B. The length of this slit determines the width of the image element to be written.

By suitably choosing the distance between the knives A and B and the objective 7 on the one hand and that between the objective 7 and the photographic plate 1 on the other, a highly defined reduced image of the opening between the knives A and B is produced on the photographic plate 1.

The assembly of the projection system (4, 5, 7) and of the rotatable disc 6 may be moved relative to the photographic material in the writing direction x , for example by moving the photographic material in its plane. The

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knife A is stationary with respect to the optical axis and hence follows the movements of the projection system. The knife B, however, is movable relative to the projection system and hence to the knife A also. The desired absolute movement of the knife B and its desired movement relative to the knife A are computed in a device, not shown, and the signals resulting from the computation are applied to the device controlling the movement of the knife B, which device is designated 8 in Figures 3 and 4. Figures 3 and 4 show the case in which writing is effected in a direction from left to right. Obviously, writing may alternatively be in a direction from right to left. In this event, the knife B will be stationary with respect to the projection system and the knife A will be movable relative to this system. If desired, both knives A and B may be controlled.

A mirror system mounted in a rotatable drum 9 is arranged between the knives A and B and the objective 7. The axis of rotation substantially coincides with the optical axis of the objective 7. The mirror system comprises a reflecting prism 10 and a plane mirror 11. The incident beam is first reflected by a reflecting surface 12 to the plane mirror 11. This mirror reflects the beam to a reflecting surface 13, and this surface directs the beam on to the objective 7. When the drum 9 and hence the mirror system 10, 11 are rotated, A' and B' will be rotated. Thus, writing may be effected in any desired direction.

In a practical embodiment of the apparatus according to the invention, an area of $200 \times 200 \text{ mm}^2$ could be written with a writing speed of 10 mm per second and with accelerations and decelerations in the writing movement of 1 m per second per second. The repeat accuracy was 0.5 mm. A choice was possible from 199 writing widths, the maximum width being $1,900 \mu\text{m}$ and the minimum width being $2 \mu\text{m}$.

Possible uses of the described method and apparatus according to the invention lie in the general field of manufacture of photomasks and especially in the manufacture of photomasks for integrated circuits and large-capacity stores. The method and apparatus according to the invention may also be used for direct writing of mask patterns on a semiconductor material, without the intermediate step of manufacturing of photomasks.

So in the method of discretionary wiring approach, whereby on a chip of semiconductor material, in which chip electrical components such as transistors already have been formed, conduction patterns interconnecting the components may be directly formed, the method and apparatus also may be used.

WHAT WE CLAIM IS:—

1. A method of writing mask patterns on a photographic material by means of light, in which method a spot of light is formed from the light of a source of light by means of an opening which is substantially rectangular, said light spot being moved relative to the photographic material along paths which correspond to the mask patterns to be written, and the length of the light spot in the direction of writing is determined by two boundaries which are separately controlled so that for each infinitesimal element of a pattern element to be written the time elapsing between the passage of the initial boundary of the light spot and the passage of the final boundary of the light spot over the infinitesimal element is the same, irrespective of accelerations or decelerations in the relative movement of the light spot and the photographic material.

2. A method as claimed in Claim 1, wherein the width of the light spot at right angles to the direction of writing is determined by two adjustable transverse boundaries situated at least substantially in the plane containing the initial and final boundaries.

3. A method as claimed in Claim 2, wherein all the boundaries are projected on to the photographic material by means of a lens system.

4. An apparatus for carrying out the method of writing mask patterns by means of light as claimed in Claim 1, 2 or 3, wherein there are inserted in the path of the light from the light source to the photographic material present during the writing process two knives forming respectively the initial and final boundaries, of which knives, during the writing process, one is stationary with respect to a lens system which forms the light spot, and the other knife is movable relative to this lens system.

5. An apparatus as claimed in Claim 4, as appended to Claim 2 or Claim 3, wherein the transverse boundaries are constituted by one of a number of transparent areas of different lengths provided in the radial direction in an opaque disc which is rotatable about an axis at right angles to the plane of the disc.

6. An apparatus as claimed in Claim 4 or Claim 5, wherein there is inserted in the light path between the boundaries and the lens system a mirror system which is mounted in a rotatable drum and the axis of rotation of which substantially coincides with the optical axis of the lens system.

7. An apparatus as claimed in Claim 6, wherein the mirror system comprises a reflecting prism and a plane mirror.

8. A mask pattern manufactured by means of a method as claimed in Claim 1, 2 or 3.

9. A mask pattern manufactured by means



knife A is stationary with respect to the optical axis and hence follows the movements of the projection system. The knife B, however, is movable relative to the projection system and hence to the knife A also. The desired absolute movement of the knife B and its desired movement relative to the knife A are computed in a device, not shown, and the signals resulting from the computation are applied to the device controlling the movement of the knife B, which device is designated 8 in Figures 3 and 4. Figures 3 and 4 show the case in which writing is effected in a direction from left to right. Obviously, writing may alternatively be in a direction from right to left. In this event, the knife B will be stationary with respect to the projection system and the knife A will be movable relative to this system. If desired, both knives A and B may be controlled.

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4. An apparatus for carrying out the method of writing mask patterns by means of light as claimed in Claim 1, 2 or 3, wherein there are inserted in the path of the light from the light source to the photographic material present during the writing process two knives forming respectively the initial and final boundaries, of which knives, during the writing process, one is stationary with respect to a lens system which forms the light spot, and the other knife is movable relative to this lens system.

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6. An apparatus as claimed in Claim 4 or Claim 5, wherein there is inserted in the light path between the boundaries and the lens system a mirror system which is mounted in a rotatable drum and the axis of rotation of which substantially coincides with the optical axis of the lens system.

7. An apparatus as claimed in Claim 6, wherein the mirror system comprises a reflecting prism and a plane mirror.

8. A mask pattern manufactured by means of a method as claimed in Claim 1, 2 or 3.

9. A mask pattern manufactured by means

of an apparatus as claimed in Claim 4, 5, 6 or 7.

10 A photomask manufactured by means
- of a mask pattern as claimed in Claim 8 or
5 9.

11. A method of light-writing mask patterns, substantially as hereinbefore described, with reference to the accompanying drawings.

10 12. An apparatus for light-writing mask patterns, substantially as hereinbefore described, with reference to the accompanying drawings.

13. A mask pattern made by the method of Claim 11 or by the apparatus of Claim 12.

14. A photomask manufactured using a mask pattern as claimed in Claim 13.

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C. A. CLARK,
Chartered Patent Agent,
Century House,
Shaftesbury Avenue,
London, W.C.2.
Agent for the Applicants.

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