Dec. 15, 1970 H. SCHIER 3,547,546

MULTIPLE IMAGE FORMING DEVICE

Filed May 4, 1966

Fig. 1.

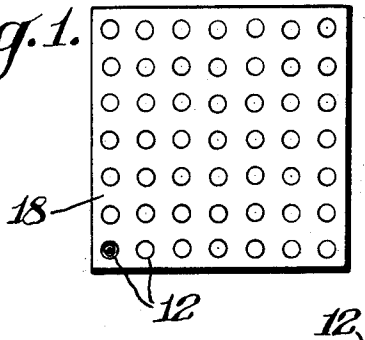



Fig. 2.

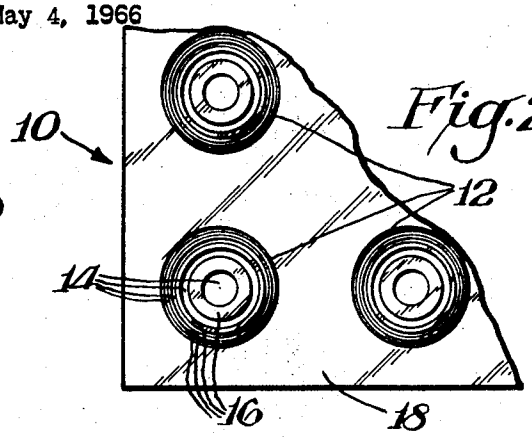



Fig. 3.

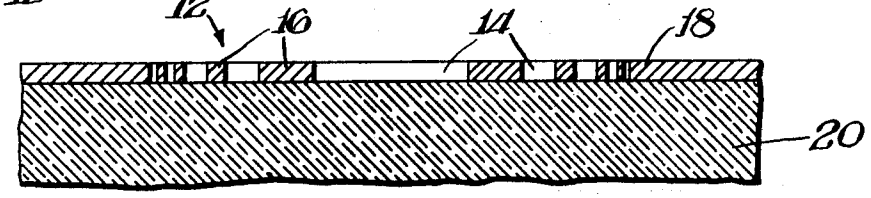



Fig. 4.

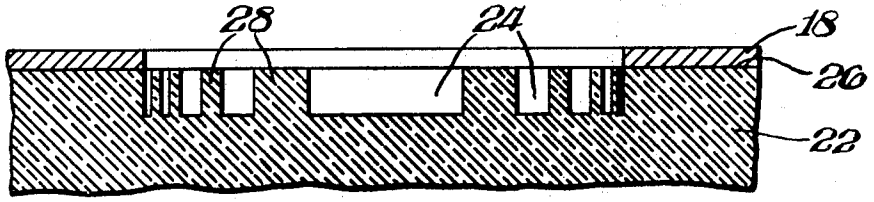



Fig. 5.

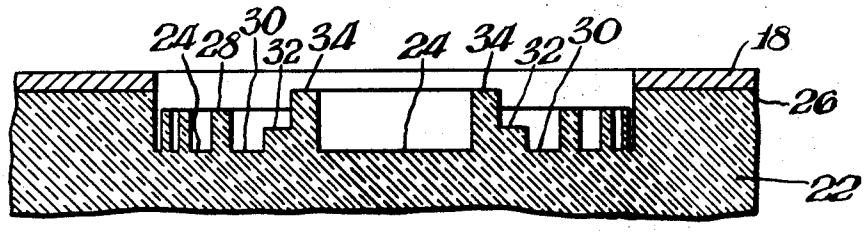



Fig. 8.

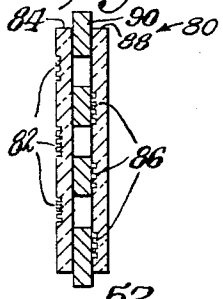



Fig. 6.




Fig. 7.

United States Patent Office 3,547,546 Patented Dec. 15, 1970



3,547,546

# MULTIPLE IMAGE FORMING DEVICE

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Int. Cl. G02b 5/18
U.S. Cl. 350—162 18 Claims

## ABSTRACT OF THE DISCLOSURE

An image forming array is provided by a zone plate matrix having a plurality of zone plates in a side by side arrangement with opaque material in registration with the spacing between zone plates.

This invention relates to an image forming device and more particularly to an image forming device for the simultaneous formation of repetitive patterns of relatively small size and a method of making the same.

Precisely oriented patterns having high resolution, high contrast and relatively small size are required in the photographic and photolithographic techniques employed in modern technology, such as in the fabrication of semiconductor and thin film devices, and microcircuits. These are generally provided by contact printing from metal or photo masks which embody the desired image array.

Present photo-lithographic techniques, however, are limited by the position repeatability of mating patterns in the step and repeat process or by the optical quality of the lens or pinhole array in the simultaneous multiple reproduction of one master pattern.

It is an object of this invention to provide an array of image forming means to simultaneously provide multiple images from one master pattern.

It is another object of this invention to provide a matrix of image forming means having high resolution and contrast, and low optical aberrations.

It is a further object of this invention to produce a device which provides reduced multiple images of high quality by means of an image forming matrix.

It is a still further object of this invention to provide a novel zone plate.

It is a still further object of this invention to provide a method of forming patterns of high resolution.

It is a further object of this invention to provide a method of forming patterns for mask production, or direct projection printing of semiconductor and thin film devices and microcircuits.

These and other objects of the invention will be apparent from the following specification taken in conjunction with the drawing, in which:

FIG. 1 is a plan view of a zone plate matrix made in accordance with the invention;

FIG. 2 is an enlarged detail view of a portion of the matrix of FIG. 1;

FIG. 3 is a view in section of one plate of FIG. 2;

FIG. 4 is a view in section of a modified zone plate constructed with a 180° phase shift in alternate zones;

FIG. 5 is a view in section of a further modification of the zone plate of FIG. 4 in which two adjacent zones are subdivided;

FIG. 6 is a perspective view of a multiple image forming device employing a zone plate matrix;

FIG. 7 is a plan view of a mask suitable for use in the structure of FIG. 6; and

FIG. 8 is a view in section of a multilayer matrix.

In accordance with the invention, a device for simultaneously forming a multiplicity of images comprises a zone plate matrix having a plurality of zone plates arranged in substantially side by side relation, and opaque areas in registration with the spacing therebetween.



A matrix of zone plates having identical optical characteristics may be provided, as well as one having zone plates of different characteristics. Thus zone plates optimized for one wavelength of radiation may be employed throughout the matrix; or may be interspersed with zone plates optimized for a different wavelength.

In one embodiment a matrix is provided by a glass plate having on one of its major surfaces a thin metal coating in which a plurality of zone plates, each consisting of several concentric annular zones of alternating transparent and opaque material, is provided by openings in the metal coating.

For increased contrast and radiation intensity at the image surface, alternate zones may also be constructed to provide a 180° phase shift of the transmitted radiation; or doublets of adjacent zones may also be subdivided to result in proportional phase shift throughout the alternate zones.

In a more limited sense an image forming device is provided by a zone plate matrix interposed between a primary or secondary source of substantially monochromatic radiation and an image receiving surface, such that the matrix forms multiple images of said source on said surface.

Briefly the method of producing a multiplicity of substantially identical images in accordance with the invention, comprises the step of exposing a zone plate matrix to substantially monochromatic radiation to form multiple images.

In a more limited sense, the method includes the steps of passing radiation from a substantially monochromatic source through a suitable condenser system, uniformly illuminating a master target with the transmitted radiation, exposing uniformly a zone plate matrix to the radiation which proceeds from the target, and exposing an image receiving surface to the radiation transmitted by each zone plate to form multiple images thereon.

An image forming device constructed in accordance with the invention comprises a zone plate wherein all zones outermost of the inner zone are of equal area.

In a further embodiment, one zone doublet is subdivided into a plurality of sub-zones of substantially equal area with the sub-zones providing a phase shift of the incident radiation proportional to the number of sub-zones within the doublet.

Referring now to the drawing and to FIGS. 1–3 in particular wherein a zone plate matrix **10** is illustrated having a plurality of zone plates **12** in a side by side arrangement. Each zone plate **12**, which is similar to that described by Fresnel in the year 1816, is a diffractory optical image forming device, comparable, but vastly superior, to a pinhole. Unlike earlier zone plates, however, only zones outermost of the inner zone need be of equal area. Thus the zone matrix **10** provides a multiplicity of optical devices, each capable of forming one image of an object or master pattern.

The zone plate **12**, like a pinhole, can be made very thin such that images formed with it are free of aberrations found in simple lenses, such as barrel or pincushion distortion and coma. In addition, spherical aberration is nonexistent. However, the zone plate is vastly superior in both resolution and contrast to the pinhole.

My theoretical studies have indicated that a zone plate is capable of producing image details, having excellent contrast, whose width equals the width of the outermost zone of the zone plate, and with diminished contrast, image details of half that width; both independent of the wavelength of radiation employed.

These investigations have further revealed, that the area in which an image of high quality (i.e. free from

astigmatism) can be formed by zone plates, changes inversely with the second to fourth power of the incident wavelength depending on the zone plate geometry; consequently the shortest practical wavelength is preferred for use in most applications. Immersion techniques may also be employed. Thus, to further decrease the wavelength, the separation between the zone plate and the image surface or a portion of it, should be filled with an immersion medium having a high index of refraction (greater than one). Solid or liquid mediums may be individually or jointly employed. For example, an immersion oil or heavy flint glass or the like may be suitable for visible light whereas quartz is suitable for ultraviolet radiation. It was also determined that only zones outermost of the inner zone need be of equal area, and that doublets of adjacent zones could be subdivided into sub-zones for increased image intensity.

In the embodiment shown in FIGS. 1–3, each zone plate **12** is formed from a series of concentric annular zones **14** and **16** of alternating transparent and non-transparent regions which decrease in width from the center outward such that all zones, with the possible exception of the innermost zone, are substantially equal in area.

In this embodiment, a thin metallic coating **18**, of chromium, Nichrome, or titanium or the like, is provided on one major surface of a suitable transparent carrier plate **20**. Each zone plate **12** is constructed by removing concentric annular portions of coating **18** to provide the transparent zones **14**; leaving the remaining coating to provide the alternate opaque zones **16** and the opaque areas between, and contiguous with, each of the zone plates **12**.

The carrier plate **20**, which provides support for the zone plates **12** and the opaque areas **18** between them, should provide minimum undesirable interaction with the radiation employed. Thus it should consist of a glass or quartz or the like having low absorption and turbidity for that wavelength. In addition, both major surfaces should be optically polished and coated with a suitable antireflection coating.

A suitable carrier, however, is not known for very soft X-rays or U.V. radiation of short wavelength, and in such cases the opaque zones would have to be suspended from the outside rim of each zone plate by a larger number of radial spokes or the like, whose width is substantially equal to that of the outermost zone.

Advantageously, a zone plate may also be fashioned with all transparent zones as illustrated in FIG. 4, in which alternate zones shift the phase of the radiation by 180° with respect to adjacent zones. This modification, which may be fabricated by removing portions of a suitable carrier plate or by removing portions of a deposited transparent layer, provides a fourfold increase in intensity at the image surface and allows shorter exposure times and improved image contrast; however, it is, of course, somewhat more difficult to fabricate.

In FIG. 4, a zone plate which employs 180° phase shift in alternate zones is illustrated. Thus one surface of a transparent plate **22** is cut or etched to provide zones **24** depressed below the plate surface **26** and zones **28** approximately coplanar with it. Zones **28** are designed to provide an increased pathlength for the transmitted radiation so that it is shifted in phase by 180° with respect to the radiation transmitted by zones **24**. For wavelengths between .2 and 1 micrometer and an optical index of refraction between 1.5 and 2, the depressed zones **24** are typically 1200 to 10,000 A.U. below zones **28**. An opaque coating **18** is also provided in registration with the spacing between adjacent zone plates. The latter may, of course, be a deposited layer as shown or a separate mask.

A further improvement in image intensity and contrast can be gained by subdividing any two adjacent zones of equal area, hereinafter referred to as zone doublets. Thus as shown in FIG. 5, a doublet can be replaced by three or more transparent sub-zones of equal area **30**, **32** and **34**. In the case of three sub-zones, the outer sub-zone **30** of each triplet provides the same phase of exiting radiation as that of similar zones such as zone **24**, while the next sub-zone **32** provides a phase shift of 120° and the inner-most of the sub-zones **34** provides a phase shift of 240°. The sub-zones may be provided in a manner similar to that described in regard to FIG. 4. Accordingly, the intensity of a zone plate employing sub-zones will be increased by approximately seven as compared with the original zone plate of Fresnel.

A further increase in intensity can be realized by subdivision of adjacent zones or doublets into quadruplets and quintuplets etc., however, the additional gain is not generally sufficient to warrant the increased fabrication problems. Similarly, each doublet could be replaced by ramp type geometry (or an exceptionally large number of sub-zones) in which the phase angle varied continuously throughout the area of the original zone doublet from zero to nearly 360°.

The described matrices can be formed by photographic and photolithographic techniques, such as a step and repeat process or other means. Thus reduced multiple images of a single master zone plate can be formed in a photoresist layer on a metal coated carrier plate and reproduced in the described opaque and transparent configuration by etching, stripping, or stencil techniques or the like. The original master zone plate may, of course, be formed by standard photographic or drafting techniques. In a similar manner, zone plates of the phase shift type may be formed. For example, phase shift layers could be deposited on a transparent carrier and zones cut by etching to a prescribed depth by stencil techniques; or photosensitive layers which provide phase shifting could be deposited and zones provided by suitable exposure and development of this layer.

In this way a matrix or array having a large number of zone plates, each having a large number of zones, may be formed. For example, a zone plate matrix having 1600 zone plates per sq. inch, with each zone plate having 30 transparent and 30 opaque zones, was formed in a nickel-chromium film on a glass carrier plate. The diameter of the zone plate and the number of zones is controlled by a number of factors, for example, the minimum zone width is limited by the minimum resolvable line width of the instruments used in the zone plate fabrication, while the diameter of the zone plate (which may be as large as to equal the step and repeat distance), is a function of the maximum image area to be covered and the wavelength of the image forming radiation. The determination of zone plate diameter and the minimum zone width fixes, of course, the number of zones. Thus the zone plate may be optimized for the wavelength to be used, the image area, the focal length and the width of image detail. It should also be noted that these design factors are used to determine the diameter and number of zones of the zone plate and do not require, or provide for, an inner zone area equal to that of each outer zone.

A matrix incorporating any of the indicated zone plates is then available for use in a multiple image forming apparatus as shown in FIG. 6, wherein monochromatic radiation **40** illuminates a master pattern or object **42** and passes, in turn, to the zone plate matrix **10**. Thereafter, each zone plate **12** forms a reduced image **44** on a light sensitive surface **46**, such as a photoresist coating, of a substrate **48**, e.g. a silicon wafer, or a photographic emulsion. Carrier plate **20** of matrix **10** may also be of material having a high index of refraction so as to provide an immersion medium disposed between zone plates **12** and the image surface **46**.

Accordingly line widths of the order of 2.5 micrometers and less have been achieved and practical limits of achievable line widths are estimated to be around ½ micrometer at the present time.

Substantially monochromatic radiation **40** may be provided by a number of means such as a gas discharge lamp **50**, e.g. a mercury vapor lamp, in conjunction with a suit-

able filter **52**. It should be understood that the radiation employed must be monochromatic only within the spectral range of sensitivity of the photosensitive image surface **46**, since radiation outside this range will have no actinic effect on the image surface. The maximum tolerable bandwidth of radiation, within the above range, is a function of the relative aperture of the zone plate. This tolerance is typically larger than one encounters in interference microscopy.

Thus the use of various sources **50** is dependent upon the sensitivity of the photoresistive coating **46** and the image or pattern size and definition required. Most conventional photo-resists are limited to wavelengths between 2500 and 4800 angstrom units and thus blue, violet and ultraviolet radiation are employed in the preferred embodiment.

As indicated earlier, larger image areas may be provided by the shorter wavelengths. Thus, for example, with a matrix of 1600 zone plates to the square inch and each zone plate having 60 zones, a 0.3 mm. diameter image was achieved with green light (5461 A.U.), a 0.42 mm. image with violet light (4358 A.U.) and a 0.85 mm. image with ultraviolet radiation (2536 A.U.).

Advantageously, each zone plate **12** and thus the array **10** has a broad focal depth which allows good acutance on a planar image surface For increased acutance, however, a conjugate field flattener (not shown) may be employed, close to the master pattern and between it and the matrix. A similar improvement in acutance can also be provided by a suitable curved master pattern, for example, pattern **42** of FIG. 6.

Uniform illumination of the master pattern **42** is required for uniform image illumination. Thus a condensing lens system **54**, or the like, may be employed between the source and target. Uniformity is further enhanced by averaging the target illumination during the exposure time such as, for example, by sweeping the illuminating radiation in a reciprocating motion across the target. This may be accomplished by moving the source, an image of the source, or the condenser or by other means. This can also be provided by positioning a compensating transparency (suitably graded) between the source and master pattern to compensate for the nonuniformity of the source. Coherent radiation should also be provided in the zone plate area by, for example, projecting an image of a suitable radiation source onto the master pattern. A collimator, or collimating system **56**, such as a lens or group of them, may also be employed between the target and the matrix to collimate the radiation transmitted to the matrix and thereby improve image quality.

The matrix and image forming apparatus can be varied in many different ways. It can be employed, for example, to make either masks or devices directly on planar surfaces. In addition, well denfied images may be formed on curved surfaces by a zone plate matrix which substantially conforms to that curved surface.

Various zone plates may also be employed in a single matrix. Thus, one or more zone plates could be provided for indexing of the matrix and substrate. These could be optimized for visible light, so that the substrate could be visibly aligned with non-actinic radiation transmitted by the indexing zone plates, and then exposed to actinic radiation to provide the desired images by means of zone plates optimized for the latter.

As indicated, one or more zone plates may be designed to provide larger area definition than others, for the same wavelength of radiation. Many of these variations could be utilized in a single matrix for use simultaneously, or for successive use in which case specific zone plates may be blocked during a particular exposure by insertion of an aperture mask **70** as shown in FIG. 7. In such a case, mask **70** may be mounted close to either surface of matrix **10** or the image surface **46** in FIG. 6, such that its apertures **72** permit the radiation from particular zone plates to operate on the image surface while opaque areas **74** of the mask block radiation of unwanted zone plates.

Advantageously, zone plate masks can be employed in conjunction with the matrix to provide varied image patterns. For example, identical images may be formed on only a portion of the image surface at one time and thereafter by repositioning the zone plate mask and exposing other zone plates to a different master pattern, different images may be interposed between those first formed. In the latter step, instead of changing the master pattern, a different wavelength of radiation could be employed to change the area of image definition. Similarly, both variations could be applied by employing the new radiation with the new master pattern.

The method of producing repetitive patterns can be altered to suit a particular need, however, it generally includes the steps of illuminating a master pattern with substantially monochromatic radiation, exposing a zone plate matrix to the radiation from the master, and exposing an image surface to that radiation transmitted by the matrix.

Additional steps may also be included, such as the masking of some of the zone plates and the subsequent exposing of the latter to a new master pattern. Furthermore, the matrix may also be moved during the exposure to scribe lines or figures more intricate than the master pattern.

Successive matrices may also be employed with additional master patterns to form varied image patterns. For example, images may be formed from a particular pattern and matrix, a second pattern and matrix is then inserted, and new images formed by repeating the exposure step. Since the image edge is well defined, the new images may link up with those intially formed to provide large composite images, or may be merely interposed between those initially provided.

In a similar manner, the second matrix could be exposed to a different wavelength, with either the original or the new master pattern, to provide a changed area of definition. In such a case, the zone plates of the latter matrix would be designed to provide this image area at that wavelength. Advantageously, all of these process variations are carried out without moving the image surface, that is the photosensitive layer, for example, on a semiconductor or device being fabricated. Obviously, the master patterns and matrices may be indexed to the apparatus and image surface by any number of means such as optical, or mechanical, or the like.

A multilayer matrix, in which a zone plate array is provided in each layer, may also be utilized to form composite image patterns without movement of the multilayer matrix or the image surface. In one embodiment as shown in FIG. 8, a multilayer matrix **80** has zone plates **82** of a first layer **84** (which are designed for its particular image distance, area definition and the wavelength to be used with it) positioned to lie in the areas adjacent the zone plates **86** of another layer **88**. Each layer is employed while other layers are masked by an aperture mask **90**, or the like.

In a further embodiment, the zone plates of one layer lie directly behind those of another, and the contiguous areas may be opaque. Each zone plate is constructed with phase shift zones, rather than opaque and transparent, such that by providing a liquid of the right index of refraction on the zone plate surface, the image forming features (phase shift zones) of the layer may be temporarily washed out and only the zone plates of the layer in immediate use (which is not liquid covered) would operate as a zone plate matrix.

Thus many different modifications of the invention are possible without departing from the spirit and scope thereof and it should be understood that the invention is not to be limited except as defined in the appended claims.

What is claimed is:

**1.** An image forming device adapted for the formation of a multiplicity of images of an object on an image sur-

face by passing radiation from said object through an image forming matrix to said image surface: said device comprising an image forming matrix having a plurality of zone plates in substantially side by side surface arrangement with opaque material in registration with the spacing between said zone plates; a source of substantially monochromatic radiation; a filter; a master pattern; a condenser; and a collimator; said filter disposed between said radiation source and said master pattern, and said condenser disposed between said filter and said master pattern so as to pass radiation from said source through said filter and said condenser to uniformly illuminate said master pattern; said matrix disposed between said master pattern and said image surface, and said collimator disposed between said matrix and said master pattern so as to pass radiation therefrom through said collimator and said matrix to said image surface such that multiple images of said master pattern are formed on said image surface.

2. A device as claimed in claim 1 wherein said plurality includes at least one zone plate optimized for a first wavelength and at least one other zone plate optimized for a second wavelength of radiation.

3. A device as claimed in claim 1 wherein at least one of said zone plates is provided by alternate phase shifting zones of transparent material.

4. A device as claimed in claim 3 wherein at least one doublet of said one zone plate has phase shifting subzones providing a phase shift of incident radiation proportional to the number of subzones within said doublet.

5. A device as claimed in claim 1 including a plurality of said zone plate matrices in a multilayer arrangement, and means for selectively operating zone plates of each layer.

6. A device as claimed in claim 1 wherein at least one of said zone plates has alternating transparent and opaque zones.

7. A device as claimed in claim 6 wherein said matrix comprises a body of transparent material, and said opaque zones and said material in registration between said zone plates is provided by a surface coating of said body.

8. A device as claimed in claim 1 including an immersion medium disposed adjacent the matrix surface which is adapted for positioning adjacent said image surface.

9. A device as claimed in claim 1 wherein said matrix includes at least one zone plate optimized to form an image having a different definition or size than that of the other zone plates, and including means for masking at least said one zone plate to block the transmission of radiation thereby during formation of a first plurality of images by means of other zone plates, and means for masking said other zone plates during formation of an image by said one zone plate.

10. A device as claimed in claim 5 wherein the zone plates of one layer are positioned to overlie areas adjacent the zone plates of another layer, and said means for selective operation includes means for moving said opaque material into masking arrangement with the zone plates of any of said layers to block the transmission of radiation of zone plates of all but one layer at a particular time.

11. A device as claimed in claim 1 including a conjugate field flattener positioned to intercept radiation from said master pattern so as to provide images of high acutance.



12. A device as claimed in claim 1 wherein said master pattern is curved to provide images of high acutance.

13. A device as claimed in claim 1 comprising at least one zone plate wherein all zones outermost of the inner zone are of different area than said inner zone.

14. An image forming device comprising a zone plate having at least one zone doublet subdivided into a plurality of sub-zones of substantially equal area, said sub-zones successively providing a phase shift of the incident radiation proportional to the number of said sub-zones within said doublet.

15. A device as claimed in claim 14 wherein three subzones replace said zone doublet.

16. A device as claimed in claim 2 wherein said image surface is sensitive to radiation of actinic wavelength, said one zone plate is optimized for said actinic radiation, said other zone plate is optimized for non-actinic radiation, said source provides radiation of said actinic wavelength, and including a second source of non-actinic radiation, means for illuminating said pattern with radiation from said second source, means for masking a plurality of said other zone plates and exposing said one zone plate to radiation of said non-actinic wavelength from said pattern for alignment of said image surface, means for illuminating said pattern with radiation from said first source, and means for masking said one zone plate and exposing said plurality of other zone plates to radiation of said actinic wavelength from said pattern for reacting said image surface to a plurality of images.

17. A device as claimed in claim 1 including means for moving said matrix during said passing of radiation through said matrix to simultaneously scribe a plurality of lines for forming images on said image surface.

18. A device as claimed in claim 1 wherein said image surface is radiation sensitive, said matrix includes a first and second plurality of zone plates, said first plurality being disposed in areas adjacent the zone plates of said second plurality, means for masking the zone plates of said second plurality while exposing said image surface to radiation transmitted by said first plurality, and means for masking the zone plates of said first plurality while exposing said image surface to radiation transmitted by said second plurality so as to form a second plurality of images interposed between a first plurality of images on said image surface.


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| | | | |
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DAVID SCHONBERG, Primary Examiner

M. J. TOKAR, Assistant Examiner

U.S. Cl. X.R.

350—167; 353—34

UNITED STATES PATENT OFFICE

# CERTIFICATE OF CORRECTION

Patent No. 3,547,546 Dated December 15, 1970

Inventor(s) Hans Schier

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 8, under References Cited United States Patents, insert

| | | |
|---|---|---|
| 1,962,474 | 6/12/34 | Baird |
| 2,679,474 | 5/25/54 | Pajes |
| 3,004,470 | 10/17/61 | Rühle |
| 3,064,519 | 11/20/62 | Shelton |
| 3,263,079 | 7/26/66 | Mertz et al |
| 3,320,852 | 5/23/67 | Parrent, Jr. et al |
| Br. 802,918 | | Jeffree |

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(SEAL)
Attest:

Edward M. Fletcher, Jr.
Attesting Officer

WILLIAM E. SCHUYLER, JR.
Commissioner of Patents