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(54) IMPROVEMENTS IN RELATING TO THE ALIGNMENT OF A PHOTO-MASK WITH RESPECT TO THE SURFACE OF A SUBSTRATE BODY

(71) We, SIEMENS AKTIENGESELLSCHAFT, a German Company, of Berlin and Munich, German Federal Republic, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

The invention relates to a method of alignment of a photo-mask relative to a wafer-like substrate in an X-ray exposure device, prior to making an X-ray exposure via said mask. Reference marks are frequently provided on the substrate, to assist in such adjustments, the mask being provided with corresponding reference windows.

Our co-pending United Kingdom Patent Applications No. 33993/76 and 30823/77 (Specifications No. 1,531,909 and No. 1,589,285) relate to methods of effecting automatic adjustment in such operations, where a detailed integrated circuit pattern is to be produced in a semiconductor substrate by means of photolithographic etching processes. In particular, in order to increase the integration density, it is necessary to keep the line width of such structures extremely small. If masks are reproduced by projected light, e.g. when a light is projected via a mask onto a photo-lacquer layer, the diffraction width of the focussing objective imposes a lower limit, below which it is not possible to produce effective patterns. For this reason, other processes have been developed, in which the mask is not exposed using visible or ultraviolet light, but a focussed image of the mask is formed on the substrate by electron beams or X-rays, as these each have a wavelength sufficiently short to ensure that any increase in the width of the lines that may be produced by diffraction phenomena during a reproduction of a mask does not have a disadvantageous effect upon the width of the lines and structures which are to be produced. An X-ray exposure is able to reproduce extremely fine structures from a mask on to a photo-lacquer layer, with detail less than one micron, for example. If integrated circuits are to be produced with structural dimensions of this fineness, a plurality of consecutive, photo-lithographic etching steps are necessary, and each mask to be used must be precisely adjusted relative to the etching pattern produced in the preceding etching process. Each adjustment must be carried out with great accuracy to ensure that a minimum error occurs during any adjustment, as described, for example, in the German Patent Specification No. 2,333,902.

The adjustment of a mask relative to a structure which is contained in a semiconductor wafer, where it has been produced with a preceding, photolithographic step, may be impeded if the treated semiconductor wafer changes its dimensions, e.g. expands during the course of the production process, so that the mask can no longer be adjusted to precisely coincide overall with the structure provided on the substrate wafer. Such behaviour of the semiconductor wafer may be caused, for example, by high temperature processing to form an oxidation of a substrate consisting of silicon, or to cause diffusion of a dopant into the semiconductor substrate. Expansions or shrinkages of this type in semiconductor wafers may amount to half a micron in the case of a semiconductor wafer having a diameter of 75 mm. This behaviour is known in the art as "wafer instability".

In order to reduce the adjustment problems caused by such "wafer instability", the prior art includes proposals such as those set out in "IEEE Trans. Electr. Dev.", Vol. ED-22, No. 7, (1975) (467—471), in which exposure processes are to be employed in which one does not expose the entire semiconductor wafer, which for example possesses a diameter of 75 mm, and then developed and etched in respective single steps, but each individual chip to be arranged on a semiconductor wafer of this type, which chip usually has a size of from 5 to 10 mm, is separately and individually structured.

The inaccuracies produced by "wafer instability" are then reduced by the ratio of the chip diameter to the wafer diameter, so that inaccuracies produced by "wafer instability" within a chip become less than one tenth of a micron, and thus no longer have a disturbing effect. This method is a so-called "individual chip process", and each chip is exposed with the aid of a reducing projection, e.g. in a ratio of 1/10, using visible light, or using an electron beam recording method. In this "individual chip process", the irradiation mask must be adjusted in respect of each individual chip, and a separate exposure must be carried out for each individual chip. For this reason, "individual chip processes" are extremely expensive, in particular when a semiconductor wafer contains from 150 to 200 individual chips. A further disadvantage of the "individual chip process" consists in that the photo-lacquer cannot be readily exposed by the use of X-rays, since the absorption of X-rays in the sensitive lacquer layers is such that the exposure times are very long (several minutes for one exposure), and this leads to uneconomically long times when from 100 to 200 individual exposures are involved.

Hitherto, therefore, the X-ray exposure method has been used only to expose an entire semiconductor wafer, in a so-called "full wafer process". Due to "wafer instability" such a "full wafer process", adjustment inaccuracies of up to 2 microns may occur, the X-ray exposure process has previously also been considered as a process which is suitable only to produce structures which are larger than 2 microns, although on account of the short wavelength of the X-rays, very much finer structures could fundamentally be produced.

One object of the present invention is to provide a method by means of which X-ray exposure can be used to produce structures having dimensions of less than 1 micron, even when "wafer instability" occurs, and by means of which it is further ensured that adjustment to allow for the inaccuracies caused by "wafer instability" can be carried out in a "full wafer process".

The invention consists in a method of aligning a photomask relative to a wafer-like substrate in an X-ray exposure device, in which an image of a mask is to be produced onto the substrate surface by projection printing using radiation from a central punctiform X-ray source, the method comprising aligning reference windows in the photomask with corresponding reference marks on the substrate by first displacing the substrate and/or mask in a plane parallel to the plane of the substrate surface to bring the projected image of said windows into substantial coincidence with said marks and then compensating for a difference in the scale of the projected reference image with respect to the scale of the reference marks by varying the magnification of the projected image until said scales are the same.

The invention is based on the recognition that those changes due to "wafer instability", and which occur in the substrate wafers in the wafer plane, are isotropic, and that consequently they can be compensated by linear increase or reduction of the mask image during the reproduction. Furthermore, the fact is exploited that the X-ray source used is punctiform, and that consequently the reproduction is effected from a central point by spherical waves, so that the reproduction scale can be modified by maintaining constant the distance between a substrate wafer and a mask, and varying the distance between the X-ray source and the mask. The matching can be effected by maintaining a fixed distance between an X-ray source and a substrate surface, but varying the distance between the mask and the substrate surface. However, it is preferable to vary the distance of the X-ray source from the mask in order to effect the adjustment, because in conventional X-ray exposure, the X-ray mask is maintained at a distance of approximately 50 microns from the substrate surface, and the X-ray source is arranged at a distance of approximately 500 mm from the mask. In order to compensate for a change in size of the substrate wafer of 0.15 microns, it is then sufficient to displace the X-ray source by approximately 10 mm., and such a displacement can be achieved with a high degree of accuracy, whereas if the distance between the mask and the substrate surface is to be varied in order to adjust for the substrate change, this variation would have to be effected to an accuracy in the micron range, which, as experience has proved, is extremely difficult and considerably less accurate than the required displacement of the X-ray source.

The invention will now be described with reference to the drawing, which schematically illustrates a photomask in an X-ray exposure device, the drawing not being true to scale.

The X-ray exposure device supports a wafer-like substrate 1, which is provided with reference marks 2, which are assumed to be displaced by a length x relative to their theoretical position 22, due to a "wafer instability". A photo-lacquer layer 3 which is to be exposed is provided over the substrate surface and the reference marks 2. Between the substrate and an X-ray source 4, a photo-mask 5 is arranged in a plane parallel to the surface of the substrate 1. This photo-mask 5 consists of a carrier 6 which is permeable to X-rays, and upon which is arranged a layer 7 which absorbs X-rays but is provided with windows defining the structure to be reproduced, together with reference windows 20 which serve to locate the reference marks 2 of the substrate during an alignment step in which the substrate and/or mask is displaced in a plane parallel to the plane of the substrate surface to bring the projected image of said windows into substantial coincidence with said marks. The distance between the mask 5 and the surface of the substrate 1, or the surface of the photo lacquer layer 3 is approximately 50 microns. At the beginning of the alignment process the X-ray source occupies a starting position 41 represented by broken lines. During a subsequent X-ray exposure, the rays emanating from the X-ray source would pass through the reference windows 20 and land beside the reference marks 2, which have become displaced from the theoretical positions 22 as a result of "wafer instability". Any necessary alignment to compensate for this difference in scale of the projected image with respect to the scale of the reference marks is then effected by varying the magnification of the projected image until the scales are the same. Preferably this is achieved by movement of the X-ray source from its initial position 41 until the X-rays passing through the windows 20 fall on the reference marks 2 on the substrate, i.e. until the respective scales are the same. The X-ray source is then in the required position 40, and a projection printing of the image on the mask can be completed.

WHAT WE CLAIM IS:—

1. A method of aligning a photomask relative to a wafer-like substrate in an X-ray exposure device, in which an image of a mask is to be reproduced onto the substrate surface by projection printing using radiation from a central punctiform X-ray source, the method comprising aligning reference windows in the photomask with corresponding reference marks on the substrate by first displacing the substrate and/or mask in a plane parallel to the plane of the substrate surface to bring the projected image of said windows into substantial coincidence with said marks and then compensating for a difference in the scale of the projected reference image with respect to the scale of the reference marks by varying the magnification of the projected image until the said scales are the same.

2. A method as claimed in Claim 1, in which any said scale deviation is compensated by varying the distance between said X-ray source and said photo-mask, the distance between the substrate surface and photo-mask being maintained constant.

3. A method as claimed in Claim 1, substantially as described with reference to the drawing.

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1589286 COMPLETE SPECIFICATION

1 SHEET *This drawing is a reproduction of the Original on a reduced scale*