1 584 005

PATENT SPECIFICATION (11) 1 584 005

(21) Application No. 24934/77 (22) Filed 15 Jun. 1977 (19)
(31) Convention Application No. 2627176 (32) Filed 15 Jun. 1976 in
(3) Fed. Rep. of Germany (DE)
(44) Complete Specification Published 4 Feb. 1981
(51) INT. CL.[3] H01J 37/14
(52) Index at Acceptance
H1D 34 4A8X 4A8Y 4B1 4B2 4B3B 4B3Y
4B5 4K2A 4K2C 4K3B 9L 9Y

(54) IMPROVEMENTS IN OR RELATING TO ELECTRO-MAGNETIC LENS ASSEMBLIES FOR USE IN CORPUSCULAR BEAM DEVICES

(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 followin statement:-

The invention relates to an electromagnetic lens assembly for use in long-focussed corpuscular beam devices, and comprising a rotationally symmetrical coil which is surrounded on its outer surface, and if necessary, also on its end surfaces, by an iron jacket.

For example, a lens of this kind may be used as a field lens in an electron-optical reduction apparatus (see Periodical "Optik"28, Issue 5, 1968/69, pages 518 to 531). With the aid of such an apparatus, devices such as integrated circuits may be formed by processing steps involving the reproduction of a transmission mask onto a wafer.

For cost purposes, it is desirable to produce several such circuits simultaneously on the wafer, or to form highly complex integrated circuits which require a large area. However, this means that large transmission masks are required.

In order to obtain a high number of image elements, any reproduction defects of the image-forming lens or of the image-forming lens system have to be as few as possible. For this purpose, a focussing lens system having two magnetic lenses with a telecentric beam path is described in "J. Vac. Sc. Technol", Vol. 12, No. 6, November/December 1975. The telecentric beam path is formed when the transmission mask is situated in the front focal plane of a first lens (intermediate lens), and the wafer is in the rear focal plane of a second lens (focussing lens) of the focussing lens system, provided that the rear focal plane of the first lens coincides with the front focal plane of the second lens. In this focussing lens system, the magnetic lenses are operated on mutually opposed but equally reduced excitation, so that any image rotation and reproduction defects are substantially eliminated.

In an optical system, there are only two defining equations relating to the focal length f, the image distance b, the object distance a and the object image scale M, so that in any case two of these four quantities can be selected freely. In the case of electron-optical projectors the focal lengths are determined by the dimensions of the device. Moreover, in the case of electromagnetic lenses the focal length is inversely proportional to the square of the reduced excitation ε ($f \sim 1/\varepsilon^2$), i.e. a change of focal length is only possible by a change of excitation.

For the production of integrated circuits it is necessary to remove the wafer from the beam path several times and to repeatedly return it to the same place, after treatment. For this purpose it may be necessary to allow for some image rotation or for thermal expansion caused by temperature variations, which will necessitate a slight change of enlargment in a subsequent processing exposure. From this situation arises the requirement for displacement of the optical centre of the intermediate lens. Because of the heavy weight of this lens and the required accuracy of position, a mechanical displacement of the lens is out of the question in normal practice.

One object of the present invention is to provide a lens assembly having a focal length which is not solely dependent upon excitation, so that a fixed lens may have its entire field-strength distribution in the axial direction electrically.

The invention consists in an electromagnetic lens assembly for use in a long-focussed corpuscular beam devices, said assembly comprising a coaxial set of rotationally symmetrical coil sections within an iron jacket, said sections being provided with connections so that they are separately excitable, and different sections extending at least partially over different portions of the longitudinal central axis. A lens assembly of this kind differs substantially from the lenses hitherto known, which have only one single curve relating focal-length with excitation. A lens assembly constructed in accordance with the invention has a whole family of such focal-length curves, which can be produced selectively by different excitation of the individual winding sections. By this means it is, firstly, possible to vary within a wide range the focal length of this lens assembly with constant overall excitation of the coils, or it is possible to maintain the focal length unaltered when the overall excitation has been altered. This new property of a lens assembly constructed in accordance with the invention offers a very important advantage for the utilisation as an intermediate lens in the focussing system for a telecentric beam path, because here it is very important that the reduced excitation of both lenses shall be equal whilst the actual excitation is mutually opposite, and that in addition to this the rear focal plane of the intermediate lens should coincide with the front focal plane of the focussing lens. In the case of constant overall excitation the focal length of the intermediate lens can be adapted exactly to the required value. Further, it may be desirable to have a small image-rotation range available for adjustment, without having to alter the focal length. As already mentioned, the wafer has to be brought back into the beam path several times, and only a rough adjustment to the old position is mechanically possible. It is well-known that a change of excitation ε by 1 (ampere-turns/volt$^{1/2}$) causes an image rotation by 10.7°. If a fine adjustment of the wafer up to 0.5° is required, then a change of excitation $\delta\varepsilon$ of about 0.05 (ampere-turns/volt$^{1/2}$) is necessary between the focussing lens and the intermediate lens. This change in excitation can be achieved when using a lens assembly constructed in accordance with the invention without changing the focal length. The compensation of enlargement and rotational chromatic aberration of the telecentric beam path by equal and opposite excitation is not noticeably impaired by excitation differences $\delta\varepsilon$ equal to 0.1 (ampere-turns/volt$^{1/2}$) or more.

Since in the case of the long-focussed intermediate lens the field strength distribution is strongly influenced by the arrangement of turns, a displacement of the field-strength distribution is possible by means of an asymmetrical current distribution in the coil. Thus a displacement of the field-strength distribution is possible by means of different excitation of the single sections of a lens coil assembly constructed in accordance with the invention, whereby the overall excitation is maintained constant. In this manner the optically effective lens centre can be displaced within the range of about 1/10 f without changing the focal length and overall excitation. This effect is equivalent to a mechanical displacement of the lens, which as already mentioned previously, can be realised only with great difficulty mechanically due to the size of the lens and due to the accuracy of the displacement required.

In the case of a focussing system with a telecentric beam path the enlargement is given by the ratio of the focal lengths. In principle, these focal lengths are determined by the dimensions of the device and cannot be altered. Consequently, a change of enlargement and thus an adaption to possible expansions or shrinkages of a wafer that is to be worked, in dependence upon temperature variations, would not be possible. With the aid of a lens assembly constructed in accordance with the invention a field displacement can be put into effect, and the focal length can simultaneously be altered in the case of constant excitation, so that the conditions of the telecentric beam path are again maintained, but at a different enlargement.

By decoupling the focal length from the excitation, or vice versa, and by the possibility of displacing the entire field-strength distribution an adaption of enlargement and a rotation adjustment of the image on a wafer workpiece can thus be effected within certain limits. The advantageous application of a lens assembly constructed in accordance with the invention is not restricted to a focussing system with a telecentric beam path, as an image rotation can also become necessary with shadow projection, for example,. When the mask and the wafer are situated in the field of the lens, then this rotation can be achieved by a change of excitation. So that the parallelism of the beam of rays between the mask and the wafer is not destroyed when changing the excitation, the focal length has to be maintained in such apparatus.

In a lens assembly constructed in accordance with the invention all sections can be provided with the same internal and external diameters and aligned about the longitudinal central axis. A division into two separately excitable sections is sufficient for the mere displacement of the field. However, a larger number of separately excitable sections are usually selected because of the decoupling of the focal length and because of the finer adjustment possibility. Alternatively, one section may be provided which at least partially overlaps a plurality of further sections in the axial direction, the further sections having an external diameter less than the internal diameter of the one section. All further sections are preferably axially symmetrically disposed about the lens centre. With the aid of this latter arrangement a displacement of the entire field can be accomplished especially easy by operating the two further sections of smaller size with equal and opposite excitation. Their overall excitation is thus zero, and does not in any way influence the excitation of the outer winding section.

In addition to this, a great number of other winding arrangements are possible. So, for example, the further lens sections can be situated outside the one section. More than two further sections can be provided. The sections can be situated on a common coil former or on separate ones.

The invention will now be described with reference to the drawings, in which:-

Figure 1 schematically illustrates a longitudinal section of an electron-beam projector for working a work-piece, using a focussing lens system with a telecentric beam path having an intermediate lens and a focussing lens which are oppositely excited to the same extent;

Figures 2 to *4* are schematic sections of three further embodiments of a lens assembly constructed in accordance with the invention;

Figure 5 is a graph showing one possible axial displacement; and

Figure 6 is a graph showing a typical family of focal-length curves.

In the embodiment shown in Figure 1, an electron beam projector 1 consists of an electron source 2, a three-stage condenser lens system 3 forming a beam which illuminates a mask 4 on an axis 5 of the device 1, after which there is a focussing lens system 6 having an intermediate electro-magnetic lens assembly 7 and a focussing electro-magnetic lens 8, which reproduces on a reduced scale the mask 4 in an image plane where there is positioned, in this example, a wafer 11. The condenser lens system 3 may use electrostatic or electro-magnetic lenses. The electro-magnetic lenses 7 and 8 have excitations which are mutually equal and opposite.

The focussing lens system 6 has a telecentric beam path, the mask 4 being arranged in the front focal plane 10 of the intermediate lens 7, and a workpiece slide carrying the wafer 11 in the rear focal plane 9 of the focussing lens 8, the rear focal plane 12 of the intermediate lens 7 coinciding with the front focal plane of the focussing lens 8. The lens 7 has a coil assembly of three separately excitable sections 7*a*, 7*b*, and 7*c* which, in this special exemplary embodiment, each have an equal number of turns, and are arranged aligned about the longitudinal central axis of the lens surrounded by magnetic sleeve 13. This sleeve 13 surrounds the outer surfaces of the sections 7*a*, 7*b* and 7*c*, and extends to include end faces 13*a* that cover the end surfaces of the two outer windings, 7*a* and 7*c*. With this lens assembly 7, as long as the total of the separate currents passing through the respective sections 7*a*, 7*b* and 7*c* is kept constant, the excitation of this lens remains constant, although the overall field can be displaced in the axial direction, and the focal length can be altered, if there is a different current distribution to the three sections. By utilising the field displacement and the change of focal length a change of enlargement can be effected in the telecentric beam path, without increasing any reproduction defects. For constant focal length, the excitation of this lens can be changed to produce a rotation of the image of the transmission mask 4 on the wafer 11. Merely by changing the respective currents in the separate sections 7*a*, 7*b* and/or 7*c* of the lens assembly 7 the image of the transmission mask 4 on the wafer can be adjusted with regard to its size and angular position.

Figure 2 shows a lens assembly 15 which essentially corresponds to the intermediate lens assembly 7 of Figure 1, that in this lens assembly 15 the coil consists of six separately excitable sections 16 to 21. Because of the greater number of separately excitable sections the range of field displacement and of focal length changes is wider. Thus for example, it is possible to simultaneously pass current through all the sections so that they all contribute to the excitation.

Figure 3 shows yet another embodiment of the invention, in the form of a lens assembly 23, the coil of which has one section 24 extending over the entire effective lens length. In the interior of this one section 24 two sections, so-called mini-lenses 25 and 26 which are arranged symmetrically about the axial lens centre. With the aid of these further sections 25 and 26 the axial field can be displaced particularly easily by operating these two sections with mutually opposed equal excitation. Their overall excitation is thus self-cancelling, and does not influence the total excitation of the lens assembly 23. Displacement of the field in one or the other direction can be effected by simple reversal of the currents in the sections 25 and 26. To vary the overall excitation and vary the focal length, different mutually opposed currents may be fed to the sections 25 and 26, or currents of the same polarity applied to the two sections, and/or there can be a change of excitation of the section 24.

In the case of the multi-section lens assemblies represented in Figures 1 to 3, the iron sleeve 13 encases the end surfaces of the coil sections, as explained with reference to Figure 1.

Figure 4 shows an embodiment with a completely cylindrical magnetic sleeve which surrounds only the outer surfaces of the coil sections to form a lens assembly 30. It has three separately excitable sections 31, 32 and 33 like the lens 7 shown in Figure 1. The sleeve 34 of the lens assembly 30 consists of a hollow cylinder which extends considerably beyond the coil sections. By extending the sleeve 34 beyond the sections any stray field of the lens, and thus those lens defects caused by stray fields are substantially reduced.

Figure 5 graphically shows the magnetic field-strength distribution that can be obtained with any of the lens assemblies 7, 15, 23 or 30, with distances along the lens axis z plotted on the abscissa with $z = 0$ at the axial centre of the lens, and the magnetic induction B indicated on the ordinate. A curve I shows the field-strength distribution to illustrate how it is shaped in the case of an excitation which is symmetrical about the axial lens centre, for example, in the case of a lens assembly 7 having the same current strength and current direction in each of the three sections *7a*, *7b* and *7c*, or in the case of the lens assembly 23 with the sections 25 and 26 being unenergised. A curve II shows how a displaced field-strength distribution can vary with the excitation of the individual windings. The shape of the curve is visibly the same, so that this field displacement is effectively equivalent to a mechanical lens displacement.

Figure 6 is a graph showing a family of focal-length curves f (ε) which can be selectively achieved by different excitation of the individual sections, the excitation ε being indicated on the abscissa on a linear scale and the focal length f on the ordinate, likewise on a linear scale. The different curves may be obtained by using a lens which corresponds to the lens assembly 15 in Figure 2, where the coil is divided into several sections that contribute to the overall excitation to different degrees. If a straight line 35 is drawn through the family of focal-length curves parallel with the ordinate, then in the case of a fixed value for the excitation this straight line intersects the individual focal-length curves at several values of the focal length, i.e. even when the excitation is constant, different focal lengths can be selected. For example, this excitation can be achieved by exciting only the two inner sections 18 and 19 in the example of the lens 15. In this way a very strong field value at the centre of the lens is obtained, with a rapid drop at the ends of the lens assembly, to give a small focal length. In another example, the outer sections 16, 17, 20 and 21 can be used for the excitation of the lens assembly 15. In this case the field-strength distribution is significantly flatter than in the preceding case, with a smaller maximum field-strength distribution at the centre giving a larger focal length. In addition to these two examples, a great number of other adjustment possibilities are available, so that the focal length can be changed continuously over a certain range in the case of constant excitation.

If a straight line 36 is drawn parallel with the abscissa, then for the case of a constant focal length this straight line intersects the focal-length curves for different excitations. From this it can be seen that in the case of a constant focal length also the excitation can be varied within a certain range. The lens assembly can be used for control of a long-focussed corpuscular beam for working a workpiece, or for the operation of electron discharge devices or corpuscular beam apparatus where control of a long-focussed beam is required.

The type of sleeve used in the Figur 3 embodiment may be used with the assemblies of sections shown in Figures 1, 2 or 3, and vice versa.

WHAT WE CLAIM IS:

1. An electro-magnetic lens assembly for use in long-focussed corpuscular beam devices, said assembly comprising a coaxial set of rotationally symmetrical coil sections within an iron jacket, said sections being provided with connections so that they are separately excitable, and different sections extending at least partially over different portons of the longitudinal central axis.

2. A lens assembly as claimed in Claim 1, in which said jacket terminates in radially extending inwardly directed end plates

3. A lens assembly as claimed in Claim 1 or Claim 2, in which all said sections have equal internal diameters and external diameters.

4. A lens assembly as claimed in Claim 1 or Claim 2, in which one said section has a length overlapping a plurality of further said sections, the external diameter of said further sections being less than the internal diameter of said one section.

5. A lens assembly substantially as described with reference to Figure 1, 2, 3 or 4.

6. Corpuscular beam apparatus comprising a beam source, a beam forming optical system and a telecentric lens system incorporating as an intermediate lens a lens assembly as claimed in any preceding Claim.

7. Corpuscular beam apparatus substantially as described with reference to Figure 1.

G.F. REDFERN & CO.,
Marlborough Lodge,
14 Farncombe Road,
Worthing,
BN11 2BT.

Printed for Her Majesty's Stationery Office,
by Croydon Printing Company Limited, Croydon, Surrey, 1980.
Published by The Patent Office, 25 Southampton Buildings,
London, WC2A 1AY, from which copies may be obtained.

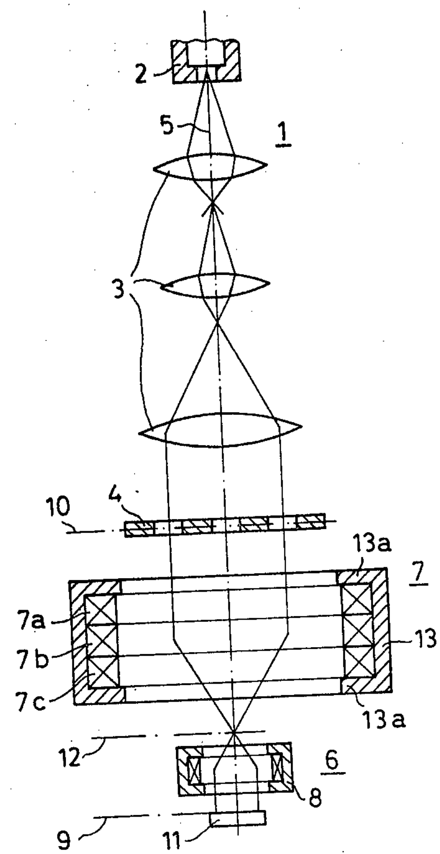

Fig.1

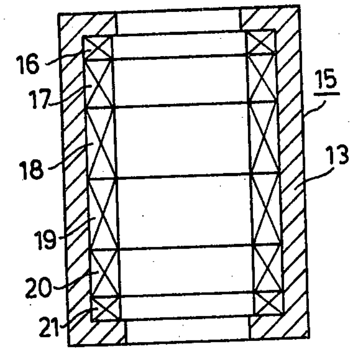

Fig.2

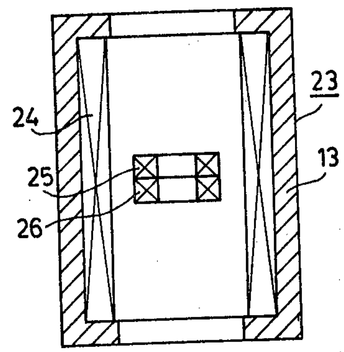

Fig.3

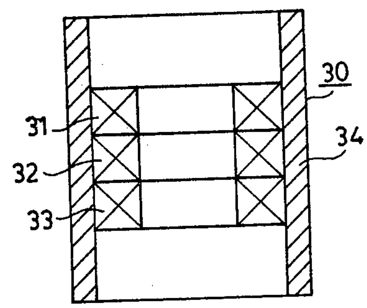

Fig.4

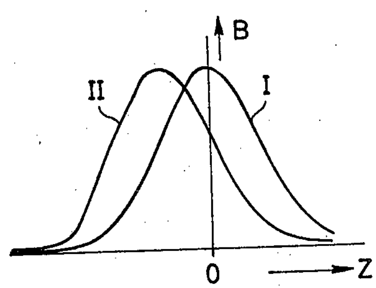

Fig.5

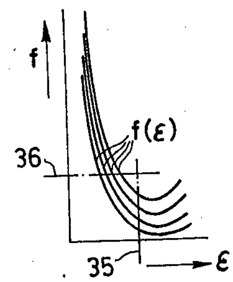

Fig.6