SCANNING SYSTEMS FOR HIGH RESOLUTION E-BEAM AND X-RAY LITHOGRAPHY

This invention pertains to high resolution lithography systems, particularly to scanning systems for X-ray and e-beam lithography, with either 1:1 imaging or n:1 reduction imaging.

The linewidth of circuit elements in integrated circuits has decreased considerably in recent years with improvements in optical lithography techniques. It is expected that optical methods will soon reach their resolution limit. To produce even smaller linewidths will require other techniques, such as X-ray lithography or electron-beam ("e-beam") lithography.

Although optical lithography is capable of patterning integrated circuits below 0.5 microns, it is clear that the wavelength of the illumination will eventually limit the resolution of the images. It is likely that X-ray lithography will become the method of choice when minimum feature sizes approach 0.1 micron, although e-beam lithography is a technique which should not be overlooked.

Proximity printing as used in conventional X-ray lithography is limited by two effects:

1) It is difficult to maintain the extremely small gaps between mask and wafer (about 5 microns) needed for high resolution; and
2) It is difficult to manufacture, test, and repair the high resolution, high aspect ratio, low distortion masks needed by this 1:1 printing system.

Projection X-ray lithography addresses the first of these issues and, when combined with image reduction, the second as well. However, while projection X-ray lithography has been demonstrated in principle, the technical requirements for useful versions of the proposed systems are beyond the present state of the art.

(1) 1:1 Imaging with X-Rays.

Fresnel zone plates for focusing X-rays are known in the art, as are methods for their fabrication. See, e.g., Vladimirsky et al., "High-Resolution Fresnel Zone Plates for Soft X-rays," J. Vac. Sci. Technol. B, Vol. 6, No. 1 (1988), the entire disclosure of which is incorporated by reference. Zone plates have severe chromatic aberration, in that their focal length is approximately proportional to the reciprocal of the wavelength. In addition, highly monochromatic X-ray sources are both weak and expensive. Consequently the use of a zone plate is effectively limited to a very small field. Therefore, the use of an array of zone plates has typically been proposed, as illustrated in FIG. **1**. Because of image inversion by each zone plate **2**, the boundaries of adjacent fields in the mask **4** do not align properly in the image **6**, as illustrated by arrows **8** and **10**. A past solution has been to use a second array of zone plates **12** for a second inversion, as illustrated in FIG. **2**. Virtual imaging from the zone plates, and "crosstalk" between fields then results in unwanted background exposure. These effects may be reduced by limiting the field of each zone plate, spacing the zone plates relatively far apart, and using a third array of zone plates **14** as field lenses. The field lens zone plates direct the light from the first array **2** so that it passes more nearly through the center of the second array **12**. Stops **16** might also be used. Each of these strategies has the disadvantages of reducing the throughput of the system, and of increasing its complexity.

(2) Reduction Imaging with X-Rays

Reduction imaging with X-rays may be performed with Fresnel zone plate arrays, or with reflecting optical systems such as Schwarzschild lenses. Schwarzschild lenses have small usable fields, and are difficult and costly to manufacture. See H. Kinoshita et al., "Soft X-ray Reduction Lithography Using Multilayer Mirrors," J. Vac. Sci. Tech., Vol. B7, No. 6, pp. 1648–1651 (1989). Other proposed mirror systems would have larger fields, but would require very large components manufactured to accuracies that are currently unattainable in practice.

(3) 1:1 Imaging with an e-beam

Prior approaches to e-beam lithography have included (a) modulated scanning electron beam and aperture imaging direct write systems, which are inherently slow, and (b) 1:1 imaging systems, illustrated in FIG. **3**, using parallel magnetic and electric fields between a mask **20** and a wafer **22**. The latter approach has the disadvantages: (1) that if the wafer is not totally flat (e.g., if it has previously been printed), the electric field will be distorted near the wafer, causing a loss in resolution and/or local distortion; (2) that electrons hitting the wafer cause secondary electrons to scatter with a range of energies, after which the secondary electrons also hit the wafer, causing background exposure and a loss of resolution; (3) that it is difficult to create a magnetic field of sufficient uniformity (to the ppm level) over the volume needed; and (4) that no correction can be made for local wafer distortion.

As illustrated in FIG. **4**, problems (1) and (2) above, but not problems (3) and (4), have previously been reduced through the use of a conductive grid **24** with many apertures, giving a zero electric field in the region between the grid **24** and the wafer **22**. The grid is typically located at or near a first focus of the electrons. The grid must be moved during exposure to prevent the shadow of the grid from being imaged on the wafer. This approach does not use scanning, and has the disadvantages (a) of needing a relatively hard-to-produce, highly-uniform magnetic field over the large region between the mask and the grid, and (b) of not correcting local distortions. See, e.g., Ward et al., "A 1:1 Electron Stepper," J. Vac. Sci. Technol. B, Vol. 4, No. 1 (1986); Ward, U.S. Pat. Nos. 4,705,956 and 4,695,732; and Ellison, U.S. Pat. No. 4,939,373.

Feldman et al., U.S. Pat. No. 4,742,234 discloses apparatus for direct-write lithography with a charged particle beam, incorporating an electric field, a magnetic field, and a conductive plate having an elongated slit. Imaging from a mask is not discussed, the data being directly entered from a computer.

In a "step-and-scan" system, different parts of the same circuit are imaged in different scans. Alignment, or overlay accuracy, on the boundaries between adjacent areas must be very precise; misalignment can be a source of circuit failure, because the effects of distortion are "concentrated" at these boundaries.

Novel systems have been developed in the present invention for high-resolution lithography using either e-beams or X-rays. These systems variously permit either 1:1 imaging (i.e., imaging without reduction), or n:1 reduction imaging.

(1) 1:1 imaging with X-rays is performed with two arrays of zone plates, with the mask at the focal plane of the first array. It is advantageous also to place plates with small apertures near one or both points of focus to block most virtual imaging and crosstalk. The aperture area is about 1% of the total plate area. The mask and