METHOD AND APPARATUS FOR X-RAY AND EXTREME ULTRAVIOLET INSPECTION OF LITHOGRAPHY MASKS AND OTHER OBJECTS

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FIELD OF THE INVENTION

This invention pertains generally to X-ray and extreme ultraviolet (EUV) lithography, particularly to masks used in X-ray and EUV lithography and methods and devices for inspecting the mask pattern, and to X-ray and EUV inspection of objects in general.

BACKGROUND OF THE INVENTION

X-ray lithography is of growing importance in the fabrication of microelectronic devices and micromechanical structures. The basic process of producing a microelectronic device involves the modification of the surface material of a semiconductor substrate, such as of silicon, in a pattern. The interplay of the material changes and the pattern defines the electrical characteristics of the microelectronic device. By reducing the dimensions of the pattern, the number of electronic devices on a single silicon chip can be increased proportionally. The shorter wavelengths of X-rays permit smaller features to be produced using X-ray lithography than is generally possible using conventional lithography with visible light. A similar process can be used to form micromechanical devices, by, for example, electroplating metal structures in a desired pattern onto a substrate. X-ray lithography is used to define the pattern on the substrate which will be doped, etched, or otherwise modified to form the microelectrical or micromechanical device.

In the basic X-ray lithography microelectronic or micromechanical device manufacturing process, a photosensitive material, such as polymethylmethacrylate (PMMA), is deposited on the substrate surface. The photoresist is X-ray sensitive and, depending on the photoresist used, portions of the photoresist that are exposed to X-rays may be removed (or left remaining) by a developing process. The microelectronic or micromechanical device is formed by etching or otherwise modifying the substrate in the areas from which the photoresist has been removed. To form a desired pattern in the photoresist, the X-rays that are used to expose the photoresist are passed through an X-ray mask that includes the pattern that is transferred to the photoresist. An exemplary portion of an X-ray mask **10** is schematically illustrated in FIG. **1**. The mask **10** is typically composed of a structural material or carrier **11**, such as of silicon nitride or silicon carbide, through which X-rays are transmitted, and X-ray absorbers **12**, made of, e.g., gold or tungsten, which are formed on the mask **10** in the desired pattern to a thickness of, e.g., approximately 0.2–0.5 μm. Much more important than the specific choice of mask materials is that the ratio of the transmission of X-rays through "clear" areas **11** and "opaque" areas **12** of the mask **10** does not fall below a specified value, R, typically 3–10. Any local change in this transmission ratio constitutes a defect in the mask pattern. For example, as illustrated in FIG. **2**, a portion **13** of the X-ray absorber pattern **12** with a transmission ratio that falls below the value R constitutes a "clear" defect, allowing the transmission of X-rays where they should be blocked. As illustrated in FIG. **3**, a portion **14** of the carrier material **11** with a transmission ratio of R or more constitutes a "dark" defect when positioned on the mask so as to block X-rays where they should be freely transmitted.

In X-ray lithography there is no reduction in the size of the mask pattern as it is transferred to the photoresist. Thus, any imperfections or defects in the mask will be faithfully recorded into the photoresist. This can cause errors and loss of functionality in the microelectronic circuit or micromechanical device being defined by the mask pattern. It is thus of critical importance to verify that the mask pattern is as fully specified by the designer, and does not contain any defects. Accurate inspection information on the mask pattern is needed.

Typically, inspection of the X-ray mask pattern is accomplished using electron beam inspection systems, such as dedicated scanning electron microscopes (SEMs). Such devices are used because of the high resolution required to properly verify the X-ray mask pattern. It is typically necessary to have a resolution of about 1/10th of the critical dimension of the pattern under inspection. Thus, for a critical dimension of 0.25 microns (corresponding to a 256 megabit DRAM) a resolution of 25 nm is required. For 1 gigabit DRAMS having a critical dimension of 0.15 microns, a resolution of 15 nm is required. The use of scanning electron microscopy (SEM) to perform the X-ray mask inspection has several important disadvantages, however. First, the substrate structure or membrane of the X-ray mask is often made of an insulating material, such as silicon nitride. Thus, a conducting layer must be deposited on the structural membrane in order to prevent charging in the SEM. This deposition not only requires an extra processing step, but could also introduce spurious defects and degrade the performance of the mask, and is preferably avoided. Secondly, the electron signal recorded from a structure may differ significantly from its X-ray transmission characteristics. This is because the electrons used in SEM only probe the near surface regions of the mask, and thus cannot be used to detect all defects. Thus, the SEM image of the mask will not necessarily represent the image of the X-ray mask pattern that would be produced by X-rays. Therefore, there is not a one-to-one mapping of defects detected using the SEM and true defects that would result from using the X-ray mask in X-ray lithography processing. Finally, the X-ray mask structure diffracts X-rays that pass through it. This causes intensity variations, and thereby line width variations, which could result in defects that cannot be observed by an SEM.

The best type of X-ray mask inspection system would be one based on the direct measurement of X-rays transmitted by the X-ray mask. Such an approach is used in optical lithography, where an optical microscope is used to measure the light transmitted by an optical mask. An analogous X-ray measurement cannot be performed, however, because of the lack of an equivalent X-ray microscope; there are no suitable or convenient magnifying optics for X-rays having wavelengths on the order of those employed in X-ray lithography (energies above 100 eV).

Extreme ultraviolet (EUV) radiation, i.e., radiation having wavelengths in the range from 5 nm to 30 nm, can also be used in the lithographic fabrication of microelectronic and micromechanical devices. In its present realization, EUV lithography utilizes a stepper (or projector) consisting of two or more EUV multilayer reflectors and an EUV multilayer reflective mask. As with X-ray mask lithography, accurate inspection of the EUV mask pattern is required to ensure that