Exhibit 14

Smith Deposition Exh. 12

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Smith

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(54) **OPTICAL PROXIMITY CORRECTION METHOD UTILIZING RULED LADDER BARS AS SUB-RESOLUTION ASSIST FEATURES**

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Related U.S. Application Data

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(51) **Int. Cl.**[7] **G03F 9/00**
(52) **U.S. Cl.** **430/5**; 430/30; 716/19; 716/20; 716/21
(58) **Field of Search** 430/5, 30; 716/19–21

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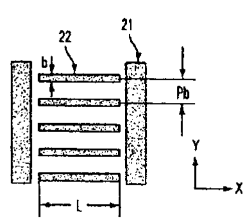
(57) **ABSTRACT**

A photolithography mask for optically transferring a pattern formed in said mask onto a substrate and for negating optical proximity effects. The mask includes a plurality of resolvable features to be printed on the substrate, where each of the plurality of resolvable features has a longitudinal axis extending in a first direction; and a pair of non-resolvable optical proximity correction features disposed between two of the plurality of resolvable features, where the pair of non-resolvable optical proximity correction features has a longitudinal axis extending in a second direction, wherein the first direction of the longitudinal axis of the plurality of resolvable features is orthogonal to the second direction of the longitudinal axis of the pair of non-resolvable optical proximity correction features.

23 Claims, 10 Drawing Sheets



actual circuit pattern developed on the photoresist layer can be significantly reduced. The degree and amount of differences in the mask and actual circuit patterns depends on the proximity of the circuit features to one another. Accordingly, pattern transference problems are referred to as "proximity effects."

To help overcome the significant problem of proximity effects, a number of techniques are used to add sub-lithographic features to mask patterns. Sub-lithographic features have dimensions less than the resolution of the exposure tool, and therefore do not transfer to the photoresist layer. Instead, sub-lithographic features interact with the original mask pattern and compensate for proximity effects, thereby improving the final transferred circuit pattern.

Examples of such sub-lithographic features are scattering bars and anti-scattering bars, such as disclosed in U.S. Pat. No. 5,821,014 (incorporated herein by reference), which are added to mask patterns to reduce differences between features within a mask pattern caused by proximity effects. More specifically, sub-resolution assist features, or scattering bars, have been used as a means to correct for optical proximity effects and have been shown to be effective for increasing the overall process window (i.e. the ability to consistently print features having a specified CD regardless of whether or not the features are isolated or densely packed relative to adjacent features). As set forth in the '014 patent, generally speaking, the optical proximity correction occurs by improving the depth of focus for the less dense to isolated features by placing scattering bars near these features. The scattering bars function to change the effective pattern density (of the isolated or less dense features) to be more dense, thereby negating the undesirable proximity effects associated with printing of isolated or less dense features. It is important, however, that the scattering bars themselves do not print on the wafer. Thus, this requires that the size of the scattering bars must be maintained below the resolution capability of the imaging system.

Accordingly, as the limits of optical lithography are being enhanced far into the sub-wavelength capability, assist features, such as scattering bars, must be made smaller and smaller so that the assist features remain below the resolution capability of the imaging system. However, as imaging systems move to smaller wavelengths and higher numerical apertures, the ability to manufacture the photomasks with sub-resolution scattering bars sufficiently small becomes a critical issue and a serious problem. Additionally, as the size of the scattering bars decrease, their ability to reduce proximity effects is reduced. Some of the problems arising with the use of scatter bars are due to the fact that the ability to include scatter bars in a design is limited, for example, by the space dimension between adjacent main features.

In addition, it has been determined by the inventor of the present application that benefits arise when assist features are positioned at frequencies that coincide with the harmonics of the frequency of the primary mask features. This implies that the assist features should be positioned at integer multiplies of the main feature frequency. For a single scatter bar solution, the scatter bar is typically placed midway between the main features. However, such placement presents a problem for dense features because the scatter bar cannot be made small enough to avoid printing. Furthermore, for semi-isolated features, the impact of a single scatter bar is generally insufficient, thereby requiring that multiple scatter bars be positioned in the space region between main features. In such instances, the desirable frequency solution is not practical as the separation between the outer scatter bars and the main feature is too small.

Accordingly, the typical solution is to place multiple scatter bars equally spaced within the space between main features. However, there are problems associated with such a solution. For example, the resulting frequency of the scatter bars is often beyond the imaging limits, thereby eliminating all but the effect of the zero diffraction order of the scatter bar. Further, if the scatter bars are placed at a frequency that matches that of the dense main features, there is an undesirable increase in the likelihood that the scatter bars will print when utilizing modified illumination techniques.

More specifically, as shown in FIG. **1**, which is an illustration of the use of prior art scatter bars as an OPC assist feature, when multiple scatter bars **11** are placed within a space opening between main features **10**, the frequency of the scatter bars is a function of the main feature space width rather than of the pitch. Although the scatter bar frequency does not coincide with that of the main features, it is generally beyond the diffraction limits of the imaging system. As a result, no first order diffraction energy is collected from the scatter bars, making the scatter bar frequency inconsequential. For example, referring to FIG. **1**, which illustrates 150 nm main features with a line:space duty ratio of 1:5, using a 248 nm wavelength and a 0.70 NA objective lens, a scatter bar size of 60 nm placed on a 187.5 nm pitch will result in three evenly spaced scatter bars **11** between the main features **10**. The resulting k_1 for the scatter bars, as defined by the resolution equation ($k_1=pNA/2\lambda$, where p equals pitch, NA equals the numerical aperture of the objective lens, and λ equals the exposure wavelength), equals 0.27, thereby effectively eliminating lens capture of the first diffraction orders when using σ values of 0.95 and below. With only zero diffraction order collection, the entire space between the main features experiences a reduction in intensity as a function of the bar width (b) and bar pitch (p_b):

$$\text{Space Reduction Intensity}=[(p_b-b)/p_b]^2=(0.68)^2=0.46 \quad (1)$$

This result is expected if the space transmission is equivalently reduced. Diffraction energy of the main features is reduced, resulting in an image with lower intensity which can allow for a mask exposure dose that more closely matches that of the other features on the mask. However, control of the intensity reduction at other values is difficult with multiple scatter bar assist features due to the constraints of the bar width and pitch values of the scatter bars.

Thus, there exists a need for a method of providing OPC assist features in a photomask which eliminates the foregoing problems associated with the use of multiple scatter bar OPC assist features.

SUMMARY OF THE INVENTION

Accordingly, it is an object of the present invention to provide a method of forming a photolithography mask having OPC assist features which allows for improved design flexibility and, in particular, improved control over the amount of space intensity reduction. In addition, it is an object of the present invention to provide OPC assist features capable of introducing a frequency component, which is substantially a harmonic of the frequency of the main features.

More specifically, in accordance with the present invention a photolithography mask is provided for optically transferring a pattern formed in the mask onto a substrate and for negating optical proximity effects. The mask includes a plurality of resolvable features to be printed on the substrate, where each of the plurality of resolvable