Exhibit 3

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

PATENT

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Applicants:	Steven R.J. Brueck et al.	Docket No.:	28516.1100
Serial No.:	08/932,428	Art Unit:	1752
Filing Date:	September 17, 1997	Examiner:	Jill Hackathorn

TITLE: **METHOD AND APPARATUS FOR EXTENDING SPATIAL FREQUENCIES IN PHOTOLITHOGRAPHY IMAGES**

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RESPONSE AND AMENDMENT

Assistant Commissioner of Patents
Box: Non-Fee Amendment
Washington, D.C. 20231

Dear Assistant Commissioner:

In response to the Final Office Action mailed March 18, 1999, of which this Response is within the shortened statutory three month response period, please amend the above reference application as follows:

IN THE SPECIFICATION:

Page 17, line 23 at the end, insert:

-- Figure 11D shows an exemplary narrow line having superior vertical sidewalls which was produced by very high spatial frequencies achieved from the nonlinearities in accordance with a preferred embodiment of the present invention.

Figure 11E shows a concept drawing of an exemplary two color separation for a typical SRAM circuit pattern demonstrating the possibilities for using spatial frequency doubling to enhance the pattern density. --.

Page 26, line 27, at the end, insert:

-- As discussed above, nonlinearities allow the extension of optics beyond the linear systems limit. As such, higher spatial frequencies can be accessed by taking advantage of nonlinearities in processing. In other words, the linear systems constraints apply to pattern frequencies, not to linewidths. This is dramatically illustrated by the micrograph in Fig. 11D that shows a 50-nm CD line on a 2-μm pitch, a line:space ratio of 1:20. The very high spatial frequencies corresponding to this narrow line are the result of photoresist process nonlinearities, the exposure aerial image was a 2-μm period sine wave. Importantly, the process latitude for printing this fine line was much greater than that for printing the 150-nm dense line:space pattern. This is a superior result in that it is always more difficult to print 1:1 patterns since these occur very near the threshold dose for developing all the way through the resist. Larger line:space ratios are closer to saturation where the process is very forgiving of small dose variations and the nonlinearities (vertical sidewalls) are larger. Thus, it is easier (greater process latitude) to print smaller CD structures at a fixed pitch.

Fig. 11E shows a concept drawing of how the aforementioned frequency doubling technique might be applied to a circuit pattern, in this case a typical SRAM pattern. The two colors indicate the patterns written in each exposure. No two features of the same color approach each other by less than 1.5CD. The spacing is less than 2 CD because of the staggered features in the SRAM pattern, so changing the design to a CD grid would allow a straightforward doubling of the pattern density. -- .

IN THE CLAIMS:

Please amend the claims as follows:

1. (Twice Amended) A method for obtaining a pattern, ~~containing~~ high spatial frequencies by combining nonlinear functions of intensity of at least two exposures combined with [an] <u>at</u> least one nonlinear processing step intermediate between the two exposures to form three dimensional patterns comprising the steps of:

coating a substrate with a first photoresist layer;

exposing said first photoresist layer with a first exposure;

developing said first photoresist layer to form a first [image] pattern in said first photoresist layer, said first [image] pattern containing spatial frequencies greater than those in [an aerial image] a two dimensional optical intensity image imposed onto said photoresist layer in said first exposure as a result of a nonlinear response of said first photoresist layer;

coating said substrate with a second photoresist layer;

exposing said second photoresist layer with a second exposure;

developing said second photoresist layer to form a second [image] pattern in said second photoresist layer, said second [image] pattern containing spatial frequencies greater than those in [an aerial image] a two dimensional optical intensity image imposed onto said photoresist layer in said second exposure as a result of a nonlinear response of said second photoresist layer;

combining said [images] patterns to provide a final [image] pattern.

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6. (Twice Amended) A method for obtaining a pattern ~~containing~~ high spatial frequencies by combining nonlinear functions of intensity of at least two exposures combined with [an] at least one nonlinear processing step intermediate between the two exposures to form three dimensional patterns comprising the steps of:

coating a substrate with a first mask material and a first photoresist layer;

exposing said first photoresist layer with a first exposure

developing said photoresist to form a first [image] pattern in said first photoresist layer, said first [image] pattern containing spatial frequencies greater than those in [aerial image] a two dimensional optical intensity image imposed onto said photoresist layer in said first exposure as a result of a nonlinear response of said first photoresist layer;

transferring said first [image] pattern into said first mask material, said first mask material comprising at least one of SiO_2, Si_3N_4, a metal, a polysilicon and a polymer;

coating said substrate with a second photoresist;

exposing said second photoresist with a second exposure

developing said second photoresist layer to form a second [image] pattern in said second photoresist layer, said second [image] pattern containing spatial frequencies greater than those in [aerial image] a two dimensional optical intensity image imposed onto said photoresist layer in said second exposure as a result of a nonlinear response of said second photoresist layer.;

transferring said first [image] pattern and said second [image] pattern into said substrate using a combined mask including parts of said first mask layer and said second photoresist;

removing said first mask material and said second photoresist.

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8. ~~15~~. (Amended) A method for increasing spatial frequency content of lithographic patterns comprising the steps of:

depositing a material;

depositing a photoresist on said material;

exposing a periodic [pattern] image in said photoresist, said periodic [pattern] image having a pitch p_{min} and a linewidth less than $p_{min}/2$;

developing said periodic [pattern] image to form a periodic pattern in said photoresist;

transferring said periodic pattern to said material;

depositing a second photoresist layer on said material;

offsetting said periodic pattern by $p_{min}/2$;

repeating said exposing, developing and transferring steps, thereby interpolating new said pattern midway between said pattern.

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4. ~~48~~. (Amended) The method of claim 1, wherein a minimum of said spatial frequencies along at least one direction in said first or second [image] pattern is smaller than $2/\lambda$.

REMARKS

Applicant responds to the Office Action mailed March 18, 1999, of which this Response is within the shortened statutory three month response period. Claims 1, 4-7, 15-23, 25-40, 48 and 49 are pending in the present Application and the Examiner rejects all of the aforementioned claims.

The Examiner objects to the disclosure due to the blank lines on page 1. Applicant thanks the Examiner for the reminder to provide this information before issuance. The Examiner next objects to Claims 1 and 6 due to a typographical error. As suggested by the Examiner, Applicant amends Claims 1 and 6 by changing "an least" to "at least".

The Examiner next rejects Claims 1 and 4-7 under 35 U.S.C. § 112 because the Examiner asserts that the Claims include subject matter not in the present specification. Applicant respectfully traverses this rejection. Application asserts that the term "aerial image" is commonly used in the art to refer to the two-dimensional optical intensity image incident on the photoresist layer. The disclosure of an optical intensity image incident on a photoresist layer is adequately supported in the spec, *inter alia*, page 10, lines 16- 30; page 14, lines 7- 12; page 18, lines 10- 25; and, page 23, lines 1- 3. However, to further clarify the Claim language, Applicant deletes the phrase "aerial image" and inserts the phrase "two-dimensional optical intensity image imposed onto said photoresist layer" in Claims 1 and 6. Moreover, to help clarify the Claim language, Applicant amends the Claims to use the term "pattern" to refer to the result of the expose/develop step and the term "image" to refer to the aerial image input of the photolithography step.

The Examiner next rejects Claims 1 and 4-7 under 35 U.S.C. § 112 because certain terms are unclear. The Examiner asserts that it is unclear how a pattern can "contain" spatial frequencies. Applicant respectfully traverses this rejection. A primary goal of the present invention is to achieve a desired pattern. It is well known in the art that any pattern can be equivalently described by specifying the amplitudes and phases of the spatial frequencies in the pattern's Fourier transform. Thus, the present application discloses a method for producing a desired pattern which contains a desired spatial frequency content comprising the amplitudes and phases of the spatial frequencies in the pattern's Fourier transform.

The Examiner next asserts that "nonlinear processing step" is unclear. As discussed above, the present invention discloses a method for producing a desired pattern. Because of the bandpass constraints of an optical system, the spatial frequencies in the aerial image are restricted (due to the diffraction limits) to be at spatial frequencies less than 2 NA/λ, wherein NA is the numerical aperture of the optical system (imaging lens) and λ is the optical wavelength. In

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interferometric lithography, an imaging lens is not required and the maximum spatial frequency in the aerial image is $2/\lambda$. Thus, a preferred embodiment of the present invention specifies a process for producing patterns with spatial frequencies larger than the aforementioned limitations.

Particularly, a "linear process" reproduces only the spatial frequencies in the previous step (not necessarily with fidelity in amplitude and phase), wherein the previous step is the aerial image. Therefore, a linear development step would result in a photoresist profile whose Fourier transform contains only those frequencies present in the aerial image. For example, in the simple case of a two beam interferometric lithography exposure, as described in Figure 5 of the specification, the aerial image contains only 3 spatial frequencies at 0, $+2k \sin\Theta$ and $-2k\sin\Theta$, wherein $k=1/\lambda$ and 2Θ is the angle between the incident beams because a linear photoresist development process yields a sinusoidal photoresist profile. In other words, a linear process is one in which the Fourier transform of the output (e.g., developed photoresist pattern for a photolithography expose/develop sequence) contains only those spatial frequencies that were present in the Fourier transform of the input (aerial image for the photolithography step).

In contrast, a "nonlinear process" is a process in which the Fourier transform of the output contains spatial frequencies that were not present in the Fourier transform of the input. For example, the higher harmonics of the frequencies in the aerial image are present in the output but not in the original aerial image. By obtaining the higher spatial frequencies using the nonlinear process, the presently claimed invention can create smaller features because the higher spatial frequencies correspond to the smaller features. As is best shown in Figure 5 of the present application, the nonlinearity associated with the photoresist exposure and development process produces higher harmonics (multiples) of the fundamental frequency in the aerial image. As is known in the art, the higher harmonics allows the sharpening of the sidewalls.

The Examiner asserts that it is unclear how the first or second images can have spatial frequencies greater than those in the aerial images. For clarification, the nonlinearity does not produce a pattern with more lines; rather, the number of lines is fixed by the spatial frequency of the optical exposure (aerial image). However, Applicant asserts that changing the line-to-space ratio of the photoresist pattern by changing the exposure parameters, changes the relative intensities of the spatial frequency components in the Fourier transform.

Moreover, to respond the Examiner's questions about the procedure and to clarify the explanation of the nonlinearity process, Applicant adds text and Figure examples of applying nonlinearities to structures. Particularly, the text and Figures describe the use of nonlinearities for producing high frequencies thereby achieving, for example, a narrow line with superior vertical walls, as shown in Figure 11D (the micrograph was produced before the filing of the present patent application), and a typical SRAM circuit pattern with enhanced pattern density, as shown in the concept drawing of Figure 11E. Because the text and Figures simply provide further examples to clarify the previously disclosed frequency multiplying techniques, no new matter is added by the text or Figure amendments.

The Examiner next asserts that Claims 1, 6, 15 and 27 are rejected under the judicially created doctrine of double patenting over Claim 1 of U.S. Patent No. 5,705,321. Applicant respectfully traverses this rejection. Applicant asserts that the use of frequency doubling to obtain a denser pattern and the redistribution of Fourier intensities to obtain square two dimensional holes at the resolution limit with square profiles, as disclosed in the presently claimed invention, is not disclosed in the '321 Patent. However, in order to expedite prosecution of this case, Applicant submits with this Response a Terminal Disclaimer in compliance with 37 CFR 1.321(c).

The Examiner next rejects Claims 1, 4-7, 15, 17-20, 23, 25-27, 29-32, 35-37 and 39 under 35 U.S.C. § 102(e) as being anticipated by Brueck, et al. (U.S. Patent No. 5,705,321). Applicant respectfully traverses this rejection. As set forth above, Applicant submits a Terminal Disclaimer with respect to the '321 Patent; therefore, the Examiner's rejection with respect to the '321 Patent is now moot.

The Examiner next rejects Claims 16, 28, 40, 48 and 49 under 35 U.S.C. § 103(a) as being unpatentable over Brueck (U.S. Patent No. 5,705,321) as applied to the aforementioned Claims, and further in view of Gardner, et al. (U.S. Patent No. 5,801,075). Applicant respectfully traverses this rejection. As set forth above, Applicant files a Terminal Disclaimer with this response; therefore, this rejection is now moot. Moreover, while the '321 Patent discloses the results of a first exposure and develop step (e.g., line width much less than p/2), the presently claimed invention obtains fine lines which are closer to each other. The disclosure of the '321 Patent uses additional exposures to isolate areas or otherwise incorporate lower frequency information. In contrast, the presently claimed invention repeats the exposure with a phase shift.

The Examiner next rejects Claims 21 and 33 under 35 U.S.C. § 103(a) as being unpatentable over Brueck and further in view of Ausschnitt (U.S. Patent No. 5,790,254). Applicant respectfully traverses this rejection. As set forth above, Applicant submits with this response a Terminal Disclaimer; therefore, the rejection is now moot.

The Examiner next rejects Claims 22 and 34 under 35 U.S.C. § 103(a) as being unpatentable over Brueck and further in view of Hosono, et al. (U.S. Patent No. 5,486,449). Applicant respectfully traverses this rejection. As set forth above, Applicant submits with this response a Terminal Disclaimer with respect to the Brueck reference; therefore, the rejection is now moot.

The Examiner next rejects Claim 38 under 35 U.S.C. § 103(a) as being unpatentable over Brueck and further in view of Dalton, et al. (U.S. Patent No. 5,116,718). As set forth above, Applicant submits with this response a Terminal Disclaimer with respect to the Brueck reference; therefore, the rejection is now moot.

Upon entry of the foregoing amendments, Applicant asserts that the present patent application is now in condition for allowance and respectfully requests a Notice of Allowance. No new matter is added by the foregoing amendments. If the Examiner has questions related to this Response or the Patent Application, please do not hesitate to call the undersigned attorney.

Respectfully submitted,

Dated: May 18, 1999

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