Exhibit 5

Response and Amendment, January 14, 1999

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

PATENT

#16B
Nelson
1/28/99

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**

RESPONSE AND AMENDMENT

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

Dear Assistant Commissioner:

In response to the Office Action mailed October 14, 1998, 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 1, line 16, replace "U.S. Patent Application No. 08/407,067" with -- U.S. Patent No. 5,759,744 --.

Page 1, lines 18 and 19, replace "(CIP filed March 13, 1995)" with -- (issued June 2, 1998) --.

Page 1, lines 21 and 22, replace "divisional filed March 13, 1996" with -- a continuing application was filed on July 15, 1998 --.

Page 1, line 25, replace "_____" with -- 5,705,321 --.

Page 1, line 27, replace "_____" with -- January 6, 1998 --.

Page 23, line 5, replace "array 18 of Figure 12B" with -- the array structure of Figure 1 --.

Page 23, line 23, replace "8C" with -- 9C --.

Page 24, line 16, replace "9B" with --10B and 10C --.

Page 24, line 18, replace "48" with -- 68 --.

IN THE CLAIMS:

Please cancel claims 2, 3 and 24 without prejudice to filing one or more claims of similar subject matter in one or more patent applications.

Please amend the claims as follows:

1. (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 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 in said first photoresist layer, said first image containing spatial frequencies greater than those in an aerial 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 in said second photoresist layer, said second image containing spatial frequencies greater than those in an aerial 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 to provide a final image.

[applying thresholding nonlinearities individually to said first and said second images; multiplying said first and said second images.]

6. (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 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 in said first photoresist layer, said first image containing spatial frequencies greater than those in aerial 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 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 in said second photoresist layer, said second image containing spatial frequencies greater than those in aerial 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 and said second image 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.

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

depositing a material;

depositing a photoresist on said material;

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

developing said 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 [the above steps] said exposing, developing and transferring steps, thereby interpolating new said pattern midway between said pattern.

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19 ~~27~~. (Amended) A method for multiplying the spatial frequency content of a one-dimensional line/space pattern consisting of the steps of:

providing a substrate;

depositing a material on said substrate;

depositing a photoresist on said material;

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

transferring said periodic pattern into said material by a process step

removing said first photoresist layer;

depositing a second photoresist layer;

exposing said second photoresist layer with said periodic pattern offset by $p_{min}/2$;

repeating the [above] exposing, developing and transferring steps N times with offsets of p_{min}/N, thereby interpolating *N* new said patterns equally spaced midway between said pattern.

etching exposed said material down to a predetermined depth, thereby transferring said pattern through said material;

transferring said pattern into said substrate.

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29. ~~31~~. (Amended) The method of claim 19 ~~27~~, wherein said [pitch p_{min} includes at least about 1/2 of a smallest dimension of said substrate] pattern size avoids overlapping of pattern features upon doubling of said frequency.

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31. ~~39.~~ (Amended) The method of claim ~~27~~ 19 further comprising the step of allowing about 100nm between adjacent said [storage nodes] patterns.

32. ~~40.~~ (Amended) The method of claim ~~27~~ 19, wherein said step of depositing a [dielectric] material includes depositing an NO layer.

Please add the following new claims 48 and 49:

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

5 ~~49~~. (New) The method of claim 1, wherein said intermediate nonlinear processing step enables a frequency distribution of said pattern which is altered from frequency distributions of only said first and said second exposure.

REMARKS

Applicant responds to the Office Action mailed October 14, 1998, of which this Response is within the shortened statutory three month response period. The Examiner rejects claims 1-7 and 15-40 and the Examiner withdrew claims 8-14 and 41-47 from consideration. Applicant confirms its election of Group I, namely claims 1-7 and 15-40; however, Applicant asserts that the election was not made without traverse.

The Examiner objects to the disclosure due to various informalities. As requested by the Examiner, Applicant amends the specification to reference the appropriate patent and serial numbers for the patents and patent applications cited in the background on page 1. Because the Applicant desired to file this Response within the shortened statutory response period to avoid late fees, Applicant was unable to determine the application numbers for Page 1, lines 6 and 9; however, Applicant will provide this information before issuance of the present patent application.

Applicant also clarifies page 23, line 5 by amending the specification to indicate that the pitch of the array of Figure 1 is being produced by the sequence in Figures 9A-9E. Applicant also amends the specification on page 23, line 23 to clarify that Figure 9C appropriately shows hard mask 44. Applicant also clarifies page 24, lines 16 and 18 by amending the specification to indicate that the process is shown in Figures 10B and C and the periodic pattern is indicated by reference numeral 68.

The Examiner objects to claim 24 under 37 C.F.R. 1.75(c) because the Examiner asserts that claim 24 is dependent upon claim 15 which already claims repeating the steps. Because the Examiner agrees that the repeating step of claim 15 covers the repetition of the steps N times, Applicant cancels claim 24 to avoid redundancy.

The Examiner next objects to claims 39 and 40 due to insufficient antecedent basis. To clarify the claim language, Applicant amends claim 39 by clarifying that the step allows 100nm between adjacent "said patterns." Applicant also amends claim 40 to conform to claim 27, from which it depends, by reciting the step of "depositing a material".

The Examiner next rejects claims 1-3, 6, 15, 27 and 37 under 35 U.S.C. 112. Applicant respectfully traverses this rejection. The Examiner asserts that the preamble of claims 1 and 6 is confusing. To clarify the claim language, Applicant amends claim 1 to disclose that the invention includes "a method for obtaining a pattern containing high spatial frequencies ..." to further explain that the present invention forms a pattern, wherein the pattern contains high spatial frequencies. Applicant similarly amends claim 6 to further clarify claim 6.

The Examiner next states that "applying thresholding nonlinearities" and "multiplying said first and second images" as recited in claim 1 are unclear. The presently claimed invention uses nonlinear processes between exposures, and as such, the application of threshold nonlinearities occurs during the development process with the end result of the process being the multiplication of the images. Accordingly, to further clarify the claim language, Applicant amends claim 1 by adding that the "first image containing spatial frequencies greater than those in an aerial image imposed onto said photoresist layer in said first exposure as a result of a nonlinear response of said first photoresist layer". Applicant also adds similar language to clarify the second image description in claim 1. Moreover, Applicant also amends the preamble

of claim 1 to state that "at least one nonlinear processing step intermediate between the two exposures". Applicant similarly amends independent claim 6 for the same reasons as set forth above for further defining claim 1.

The Examiner next states that the phrase "spatial frequencies that are not present in said exposing steps" is unclear. Applicant asserts that the sequence of steps in claim 1 produces spatial frequencies that are not in the aerial images of the two exposures. Even for a single exposure, the resulting spatial frequencies are not in the aerial image. More particularly, the thresholding nonlinearity of the resist includes harmonics of all of the frequencies present in the image. For a simple grating and incoherent illumination, the aerial image is $1+A\cos(2\pi x/p)$ where A is a constant (vs. position) that depends on the grating frequency ($1/p$). There are only two frequencies in this aerial image: 1) a dc term (zero frequency) and a single high frequency $1/p$. The final pattern in the resist is

$$\sum_n B_n \cos(2\pi nx/p + \varphi_n)$$

where B_n and φ_n are constants that collectively describe the nonlinear response of the photoresist. Many frequencies exist including the two in the aerial image ($n = 0$ and $n = 1$) as well as many other higher frequencies ($n > 1$). The increase in frequency depends on the significant terms, namely on the ratio B_n/B_0. If there are more frequencies in the aerial image, the corresponding expression has all of the harmonics and combinations of harmonics. For two frequencies oriented in the same direction, the aerial image is:

$$\sum_n \sum_m B_{n,m} \cos(2\pi nx/p_1 + 2\pi mx/p_2 + \varphi_{n,m})$$

where n and m span over negative as well as positive integers. The exact coefficients ($B_{n,m}$, $\varphi_{n,m}$) depend on the exposures and the nonlinearities. The important point is that these combinations arise from the nonlinear processes and are not present in the aerial images.

Accordingly, to clarify the claim language in accordance with the foregoing explanation, Applicant amends claim 1 to clarify that the "spatial frequencies greater than those in an aerial image imposed onto said photoresist". Because claim 1 further clarifies the type of spatial

frequencies, Applicant cancels claim 2 which is now redundant due to the amendments to claim 1.

The Examiner next objects to claim 3 because the Examiner asserts that the phrase "spatial frequencies that are larger than $2/\lambda$ in all three spatial directions" is unclear. Applicant asserts that a maximum spatial frequency supported by optical propagation is $\lambda/2$ (as discussed in the Summary section), wherein the intensity pattern corresponds to the interference of counter-propagating beams. The presently claimed invention alters the frequency distribution of the final structure by (i) increasing the pattern density in the plane of the wafer to periods less than $\lambda/2$ in at least one direction (interpolation of the gratings); and (ii) changing the features of a pattern in a desirable way without increasing the density such as, for example, round holes to square holes. To further define the foregoing invention, Applicant cancels claim 3 and adds new claims 48 and 49. New claim 48 sets forth the objective for the interpolation method, while new claim 49 sets forth both the interpolation and the change of features without the increase of density.

The Examiner next objects to claim 15 because the term "substantially" is vague and indefinite. Applicant asserts that claim 15 merges two grating patterns to produce a final grating pattern at twice the spatial frequency. As such, a linewidth less than $p_{min}/2$ is used. To clarify the claim language, applicant eliminates the term "substantially" from the claim element. The Examiner also states that "repeating the above steps" in unclear. To clarify the language of claim 15, Applicant further defines the repeating step as including "exposing, developing and transferring steps".

The Examiner next objects to claim 27 because of the terms "critical dimension" and "much less." To clarify the claim language, Applicant explains that the linewidth should be less than $p_{min}/2$. Moreover, the Examiner objects to the phrase "repeating the above steps N times". To further clarify the claim language, Applicant sets forth the specific steps which are repeated, namely the exposing, developing and transferring steps. The Examiner next objects to claim 37 due to the description of the pitch. Upon entry of the foregoing amendments, Applicant amends claim 37 to recite that the pattern size is small enough such that the doubling of the frequency would not result in an overlapping of the pattern features. For example, if an object is a line-space pattern with a period p, without any doubling, an equal line-space grating would have a

linewidth p/2. If the period is doubled, the line width has to be no more than p/4 to allow a full line and space into each half of the first structure.

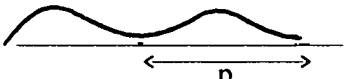
The Examiner next rejects claims 1, 15 and 27 under double patenting over claim 1 of U.S. Patent No. 5,705,321. Applicant respectfully traverses this rejection. Applicant asserts that very significant differences exist between the presently claimed invention and U.S. Patent No. 5,705,321. The presently claimed invention discloses a nonlinear step such as developing (claim 1) or developing and transferring (claim 15 and 17) between the two exposures. The '321 Patent simply discloses multiple exposures in the same level of photoresist without any processing in between the steps. The foregoing distinction is extensively discussed in the present application on page 13, line 13 - page 14, line 5.

More particularly, the present invention uses a sequence of at least two optical exposures separated by some nonlinear processing steps. The method produces images with a spatial frequency content that is different than that which would have been produced by a conventional multiple exposure process (which is disclosed in some of the cited art) followed by the nonlinear processing of developing and pattern transfer. Patterns with higher density which can be achieved with existing exposure processes, such as the frequency doubling described in Figures 9-11, exemplify the substantial benefits of the presently claimed invention. The presently claimed invention also changes magnitudes and phases of the Fourier coefficients between the process described by (expose, expose, nonlinear) and (expose, nonlinear, expose, nonlinear). Figures 6 and 7 exemplify this result by the demonstration of the round hole to square hole transition. Both of the patterns have the same spatial frequencies; however, the round (or elliptical) holes have a distribution of frequencies that radiates outward from the center of frequency space, while the square holes have frequencies only in the x and y directions perpendicular to the sides of the holes. The roll-off of the magnitudes of the Fourier coefficients is a more rapid function of the magnitude of the frequency in the round case than in the square case.

The Examiner next rejects claims 1, 4-7, 15, 17-20, 23-27, 29-32, 35-37, and 39 under 35 U.S.C. 102(e) as being clearly anticipated by Brueck et al. (U.S. Patent No. 5,705,321). Applicant respectfully traverses this rejection. As stated above, the '321 Patent simply discloses

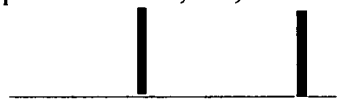
multiple exposures in the same level of resist without processing between the steps, while the present invention claims nonlinear steps such as developing (claim 1); or developing and transferring (claims 15 and 27) between the two exposures. In the presently claimed invention, patterns with higher density are achieved with exposure processes such as the frequency doubling described in Figures 9-11. The '321 Patent discusses nonlinearities which were used to make the lines thinner, but the nonlinearities did not increase the density of the structures as shown below:

Aerial image

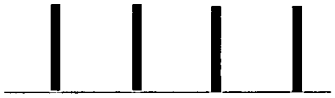


Single grating after exposure and transfer

Single grating after nonlinear processes in 5,707,321



Freq. Doubled grating after 5,705,321 and this disclosure.



Moreover, the '321 Patent allows for small lines, but the '321 Patent does not interpolate the patterns to get a denser pattern. The Examiner asserts that Figures 2 and 3 of the '321 Patent show that the linewidth is much less than half of the pitch; however, the '321 Patent does not disclose any method to create a pattern with a fundamental period of p/2, and instead, the '321 Patent only discloses a fundamental period of p.

The Examiner next rejects claims 2 and 3 under 35 U.S.C. 103(a) as being unpatentable under Brueck et al. (U.S. Patent No. 5,705,321) in view of Heise et al. (U.S. Patent No. 4,859,548). Applicant respectfully traverses this rejection. Applicant asserts that the Heise reference refers explicitly to two exposures in the same photoresist level without any

intermediate nonlinear steps. As discussed above, exposures in the same photoresist level without any intermediate nonlinear steps doe not allow frequency doubling. The Heise reference provides for a phase shift between different segments of a grating that is accomplished by a simple moiré interference pattern of two gratings written in the same level of resist. In contrast, the presently claimed invention includes a nonlinear step between the two exposures.

The Examiner next rejects claims 16, 28 and 40 under 35 U.S.C. 103(a) as being unpatentable under Brueck et al. (U.S. Patent No. 5,705,321) and further in view of Gardner et al. (U.S. Patent No. 5,801,075). Applicant respectfully traverses this rejection. Because claims 16, 28 and 40 depend from independent claims 15, 27 and 27, respectively, claims 16, 28 and 40 are differentiated from the cited art for the same reasons as set forth above for differentiating the independent claims from the cited art.

The Examiner next rejects claims 21 and 33 under 35 U.S.C. 103(a) as being unpatentable under Brueck et al. (U.S. Patent No. 5,705,321) and further in view of Ausschnitt (U.S. Patent No. 5,790,254). Applicant respectfully traverses this rejection. Because claims 21 and 23 depend from independent claim 15, claims 21 and 23 are patentably distinct from the cited art for the same reasons as set forth above for differentiating the independent claims from the cited art. Moreover, the unique combination of lithographic steps (interferometric for optical or imaging interferometric or even proximity printing) and nonlinear processes, as discussed in the specification on, *inter alia*, page 20, lines 17-24, is novel and not obvious.

The Examiner next rejects claims 22 and 34 under 35 U.S.C. 103(a) as being unpatentable under Brueck et al. (U.S. Patent No. 5,705,321) and further in view of Hosono et al. (U.S. Patent No. 5,486,449). Applicant respectfully traverses this rejection. Applicant asserts that the Hosono reference uses an image reversal process which includes two exposures separated by a reversal process that can be nonlinear. However, the reversal process is a "flood exposure" which does not contain any spatial information (Figure 5, Column 4, lines 30-50). In contrast, the presently claimed invention includes spatial information in both exposures. Moreover, because claims 22 and 34 depend from independent claims 15 and 27, respectfully, Applicant asserts that claims 22 and 34 are differentiated from the cited art for the same reasons as set forth above for differentiating the independent claims from cited art.

The Examiner next rejects claim 38 under 35 U.S.C. 103(a) as being unpatentable over Brueck et al. (U.S. Patent No. 5,705,321) further in view of Dalton et al. (U.S. Patent No. 5,116,718). Applicant respectfully traverses this rejection. Applicant asserts that, because claim 38 depends upon independent claim 27, claim 38 is distinguished from the cited art for the same reasons set forth above for differentiating independent claims from the cited art. Moreover, the presently claimed invention of combining lithographic steps with nonlinear processes is novel and not obvious; therefore, the use of contact patterning in the present lithographic steps is also patentably distinct.

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: January 14, 1999

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